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WOOD PIPE FOR CONVEYING WATER FOR IRRIGATION.

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INTRODUCTION.

During the period subsequent to 1880, the manufacture of wood pipe has grown to be an industry of considerable magnitude, and the use of such pipe is a matter of economic importance. On the part of many there has been some skepticism as to the merits of wood for water conduits. On the other hand, there are those who have had too much confidence in it. As a consequence, the value of wood pipe has often not been adequately appreciated, while in other instances it has been overrated. Many points upon which opinions differed at the beginning could be settled only upon the evidence of time and experience. Such experience, extending over a period of more than 30 years, affords a great deal of information bearing upon various points which have been and are still to some extent debatable.

The facts relating to the use of wood pipe and practice in its construction and operation during this period should, if gathered together and carefully analyzed, be sufficient to settle most of the disputed points and establish its status beyond further serious question. That there is need of such information is evident. The capital already invested in wood-pipe lines throughout the United States amounts to many millions of dollars, and this amount is being increased annually. Protection of present investments, therefore, demands that existing pipe lines be maintained and operated in accordance with what experience has shown to be the practice most favorable to long life; and future investments should be safeguarded by and profit from all available knowledge bearing upon the design, location, and maintenance of such pipe lines.

That advantage of available knowledge has not in every instance been taken may be seen by inspection of much recent work. This has doubtless been due largely to the difficulty of obtaining desired

NOTE.—This bulletin will be of interest to irrigation engineers, owners of irrigation works, water power companies, and water departments of municipalities.

information and in part to carelessness or bad judgment. In connection with irrigation projects many expensive wood-pipe lines have been built, perhaps according to good design and careful location, and then turned over to operatives who have no knowledge of how to maintain them properly. For this reason it is especially important to the irrigation interests of the West that such knowledge be made readily available.

Recent investigations have included the inspection of many pipe lines throughout several Western States; interviews and correspondence with manufacturers, builders, and operators of wood pipe; and a review of published data bearing upon the subject. It is believed that the findings should be helpful in arriving at a proper estimate of the possibilities as well as the limitations of wood pipe for several classes of service; that they should be of special value to all who are interested in the construction or maintenance of irrigation projects. The presentation of such findings, in the hope that the foregoing may be true, is the purpose of this bulletin. For much of the information acknowledgment is due to many engineers, managers of waterworks, irrigation systems, power companies, and pipe factories, to all of whom the writer wishes to express appreciation and thanks.

HISTORY.

The first use of wood for water pipe appears to have been several centuries ago. It is said that 400 miles of "pump logs" were laid in London in 1613, and it is known that the use of wood pipe for municipal waterworks was common in eastern cities of this country more than 100 years ago.

The primitive wood pipe was usually of elm, pine, spruce, or other soft wood which was easily bored, and the holes seldom exceeded 6 inches in diameter, though it is said that at Philadelphia oak logs up to 3 feet in diameter were used with bores of from 6 to 12 inches. The logs were cut into lengths up to 12 feet. Boring was done by hand.[1] This primitive type of pipe has been made in places within quite recent years, but its manufacture declined rapidly after 1820 with the almost universal adoption of cast-iron pipe which, by new processes, could be made in sizes much larger than the wood pipe of that time.

In 1885, A. Wyckoff, of Elmira, N. Y., patented a boring machine for making pipe from solid logs. The product of his factory and of others using the machines secured gradual recognition, first locally, and later somewhat generally, in the mining districts of Pennsylvania and elsewhere, for use under conditions where acids injurious to cast iron and steel were encountered. But the notable revival in

[1] U. S. Geol. Survey, Water Supply and Irrig. Paper 43, p. 63.

the use of wood pipe began about 1880 with the construction, according to new ideas, of what has come to be known as continuous stave pipe. The construction of continuous stave pipe was soon followed by the manufacture of stave pipe in sections and improved bore pipe, both of which have come to be known as machine-banded pipe. Continuous stave pipe and machine-banded pipe are both very extensively manufactured and used at the present time. These two types of pipe will be considered in this bulletin.

CONTINUOUS STAVE PIPE.

This type of pipe is a development of the old stave penstocks, many of which were built in the New England States, New York, and Eastern Canada from 1850 to 1870.[1] These were usually made in tapered sections, banded with flat iron bands. The sections were joined by inserting the small end of one a few inches into the large end of another. Such joints were faulty, which fact led to building pipe in which the ends of staves butted together, thus forming continuous stave pipe. This form of construction appears to have been first used in 1874.[2] The first extensive use, however, followed the construction of pipes designed and built by C. P. Allen, at Denver, Colo., about 1884.

Except in minor details, continuous stave pipe of the present day is the same as that built by Mr. Allen in the early eighties. It is essentially pipe built continuously in place, of staves having radial edges and faces milled to form arcs of concentric circles, the inner circle being of radius equal to half the nominal diameter of the pipe. The staves are held together by round steel bands secured by shoes and nuts, and the butt joints are made tight by the insertion of thin steel clips which fit into saw kerfs across the ends of the staves. This form of construction is illustrated in Plate I.

ADAPTABILITY AND USE OF CONTINUOUS STAVE PIPE.

Continuous stave pipe is adapted to the usual service required in conveying water long distances for municipal, power, irrigation, mining, or manufacturing purposes. It has a particularly wide field of usefulness throughout the West because of the low cost and ease with which the material for its construction can be procured, transported, and assembled in regions remote from railroads and difficult of access, where the expense of cast iron or other kinds of pipe commonly used in the East would in many instances prohibit their use.

In addition to its low first cost, experience has shown that wood pipe has other advantages as compared to cast-iron or steel pipe. It

[1] U. S. Geol. Survey, Water Supply and Irrig. Paper 43, p. 63.
[2] Trans. Amer. Soc. Civ. Engin. (1877), p. 69.

is not so subject to injury from freezing, settling, or expansion and contraction due to extremes of temperature, while if injury is sustained, extra material can usually be obtained readily, and repairs can be made much more quickly and with less expense than would be required for pipes of iron or steel. Furthermore, the capacity of wood pipe is probably somewhat greater than that of iron or steel of equal size, and may, under favorable conditions, increase with time instead of being reduced by tubercles and corrosion such as occur in the other kinds of pipe mentioned.

More continuous stave pipe has been used for conveying municipal water supplies than for any other purpose. The Denver Union Water Co. has been using it since 1884, and now has upwards of a hundred miles installed. Seattle has over 50 miles; Tacoma completed about 43 miles in 1912 and has built more since that time; the Butte City Water Co., prior to 1899, had installed about 30 miles; Walla Walla, Wash., has 13 miles. It is used to some extent at Astoria, Oreg.; Salt Lake City, Ogden, and Provo, Utah; Canon City, Pueblo, Loveland, Trinidad, and Fort Collins, Colo.; and in many other places in the West that might be mentioned, as well as at a few in the Atlantic States.

The use of this type of pipe in connection with power development, though as yet perhaps not so extensive, is coming to be even more general than for conveying municipal water supplies, and examples might be enumerated by the hundred of pipes in sizes from 2 feet to 14 feet in diameter that have been installed for this purpose throughout the United States, Canada, Mexico, and Alaska.

The use of wood pipe for irrigation purposes is confined to the Western States, but there are few of the more important irrigation projects of recent development on which it is not employed at least to some extent, its chief adaptability being for "inverted siphons" for carrying water across deep ravines or depressions not otherwise easily spanned. In a few instances the original gravity ditches have been entirely supplanted by continuous stave pipe. It is also very frequently used for conducting water from pumps to the points of discharge into ditches or reservoirs at higher elevations.

Continuous stave pipe has, as a rule, been restricted to service where the pressure head does not exceed 200 feet, though in many instances short sections are required to carry greater pressures rather than change to another type of pipe. A few pipes of this kind have been built for heads up to 400 feet.

DESIGNING OF CONTINUOUS STAVE PIPE LINES AND MATERIALS USED IN CONSTRUCTION.

A discussion of the theory underlying the many considerations of the economic design of wood-pipe lines is not within the scope or

purpose of this bulletin. Such discussion may be found in published transactions of engineering societies and in engineering journals. But some points relative to practice in design and use of materials will be given in the following pages.

SIZE OF PIPE.

Continuous stave pipes have been built in sizes from 10 inches in diameter up to 13.5 feet, but this form of construction is not common at present in pipes of diameter less than 20 inches. Pipes smaller than this are usually machine banded. Sizes greater than 8 feet in diameter are exceptional. The size of pipe to use in any particular place must be governed by conditions. For gravity lines the quantity of water to be carried and the available head are the controlling factors. If for conducting water from pumps, the size must be determined with reference to the economic relation between velocity or permissible friction head and power requirements. A pipe which is too small may involve an excessive expense for power, while too large a pipe would require initial investment greater than necessary.

The capacity of wood pipe is generally computed according to Kutter's formula, in which a value of "n," the coefficient of roughness, is selected somewhere between 0.010 and 0.013, depending upon conditions and the judgment of the engineer. Just what value of "n" to assume is a debatable question. Experiments are now being made to determine the carrying capacities of wood pipes and the proper coefficient of roughness to apply in such formulas as Kutter's.

As a result of measurements of flow in pipes, the following values for "n" for specific cases have been determined by various writers: Schuyler, 30-inch pipe, 0.0096; Gutelius, 24-inch pipe, 0.01; Adams, 18-inch pipe, 0.01; Adams, 14-inch pipe, 0.011; Marx, Wing, and Hoskins, 72-inch pipe, 0.012 to 0.015. Smaller values for "n" are usually assumed for small pipes than for larger ones, and there appears to be reason for believing that "n" may vary also with velocity. Moritz,[1] from measurements of pipes 4 inches to 55 inches in diameter, found $V=1.72\ D^{0.7}\ H^{0.555}$ and $Q=1.35\ D^{2.7}\ H^{0.555}$, where Q=discharge in second-feet; V, the mean velocity of flow in feet per second; D, diameter of pipe in feet; and H, friction loss per 1,000 feet of pipe.

Based either on Kutter's formula or on one of the exponential type, various tables have been prepared for convenient use in estimating the capacity of pipes, loss of head in friction, etc. Such tables may be obtained from the leading manufacturers of wood pipe.

[1] Engin. News, 68 (1913), No. 24, p. 668.

STAVES.

In designing staves economy dictates that the width and thickness be made such that stock lumber of standard sizes may be used. These are 2 by 4 inches, 2 by 6 inches, 3 by 6 inches, 4 by 6 inches, and 4 by 8 inches. Without strict adherence to the finer theoretical considerations as to thickness, etc., staves for most pipes for ordinary heads, and from 22 inches to 44 inches diameter are milled from 2 by 6 inch stock, finished 1⅝ inches in net thickness. From this up to 60 inches staves 2 inches thick are commonly used, and in some instances for pipes 72 inches in diameter. For pipes from 5 to 8 feet in diameter staves are usually 2½ inches thick. For pipes to withstand extremely high pressure and for those of extremely large size the thickness of the staves should be increased accordingly, in order to insure safety against crushing or shear of the wood due to the greater tightness of cinching required. The width will be such as to cut with least waste from the stock sizes of lumber.

Western yellow pine (*Pinus ponderosa*), Texas pine (*Pinus palustris*), spruce, California redwood (*Sequoia sempervirens*) and yellow fir (*Pseudotsuga douglasii*) have all been used for staves, but during recent years practically all pipes of this kind have been made either of redwood or fir, the other kinds of wood having proved to be less valuable for the purpose. At the present time fir is used much more extensively than redwood. It is less durable than redwood when placed in the ground under unfavorable conditions, but in other respects is considered to be just as good or better and costs materially less than redwood. The lumber for pipe should be of extra good quality. The following specifications for fir staves are typical requirements:

Staves shall be made of live timber, sound, straight grained, entirely free from all dead wood, rotten knots, dry rot, cracks, shakes, or any other imperfections or defects that might impair their strength or durability. Pitch pockets will be allowed, provided they do not extend more than one-fourth of an inch into the staves. Small, tight knots not over three-fourths of an inch in diameter, and not occurring oftener than one in 4 feet of stave will be allowed, as will sapwood on the inside of the stave so long as it does not extend more than half way through the stave at any point.

Staves may be from 10 to 30 feet in length, but not more than 10 per cent shall be less than 14 feet in length. Timber must be thoroughly seasoned, either by kiln or air drying, before being milled into staves.

Another requirement, not common, however, is that staves shall be milled from flat or bastard sawed lumber, those in which the edge grain passes through the stave in a distance less than one-half inch more than the thickness of the stave will be rejected.

Other general specifications are—

That the staves shall be dressed on both sides to true circles, and on the edges to conform to the radial lines of the pipe; that all staves shall be of uniform thickness, and each stave of uniform width throughout its entire

length; that the end of the stave shall be cut square, and shall be fitted with a saw kerf for the insertion of a metal tongue; in depth the saw kerf shall be one-sixteenth of an inch less than half the width of the tongue, and its position must be the same in all staves.

BANDS.

For bands, the usual specifications require soft steel of ultimate tensile strength equal to 55,000 to 65,000 pounds per square inch; elastic limit not less than one-half the ultimate tensile strength; elongation in 8 inches not less than 25 per cent, and the bands are required to stand bending, cold, 180° around a diameter equal to that of the specimen tested, without fracture on either side. Such steel is similar in quality to that used for steam boilers.

It is usual to specify that bands shall be provided with not less than 5 inches of cold-rolled thread or have upset ends; the idea being to insure as great strength in the threaded portion as in the body of the band. Each threaded end should be supplied with a standard hexagonal nut three-sixteenths of an inch thicker than the diameter of the band, and a plate washer of proper diameter and standard thickness.

In determining the size of bands many engineers have used a formula developed by the late A. L. Adams.[1] Four is the usual factor of safety. Bands less than three-eighths of an inch in diameter are not used. The following table prepared by Mr. Adams shows minimum sizes of pipe for which bands of several sizes are applicable.

Minimum sizes of pipe for which specified bands are applicable.

Size of band.	S equals ¼ ultimate tensile strength.	Band pressure per square inch.	E equals band pressure per linear inch.	Least external radius of pipe.	Band pressure per square inch.	E equals band pressure per linear inch.	Least external radius of pipe.
Inch.	*Pounds.*	*Pounds.*	*Pounds.*	*Inches.*	*Pounds.*	*Pounds.*	*Inches.*
⅜	1,650	650	122	13.5	750	140	11.8
7/16	2,250	650	142	15.8	750	164	13.7
½	2,950	650	163	18.1	750	187	15.7
9/16	3.725	650	183	20.4	750	211	17.65
⅝	4,600	650	203	22.6	750	234	19.6
¾	6,600	650	244	27.0	750	281	23.5

The particular style of band to use, one piece or two piece, oval head or square head, depends upon the size of the pipe, etc. Standard patterns of each, as made by one of the leading manufacturers, with weights and dimensions, are given as follows.

[1] Trans. Amer. Soc. Civ. Engin., 41 (1899), p. 27.

Dimensions and weights of standard one-piece bands.

[Dimensions in inches and weights in pounds.]

Size of band.	Kind.		Threads.			Nuts.		Washers.			Heads.		Approximate length of rod required to form 1 head.	Weight per 100 plain round rods 15 feet long.	Weights.			Total weight per 100 bands 15 feet long.
	Head.	Nut.	Diameter.	Length.	Per inch.	Short diameter.	Thickness.	Diameter.	Gauge No.	Hole.	Width.	Thickness.			Nuts per 100.	Washers per 100.	Heads per 100.	
	Button..	Square....													8.0			591.1
	..do....	Hexagonal													7.0		2.4	590.1
	Square..	Square....													8.0			591.2
	..do....	Hexagonal													7.0		2.5	590.2
	Button..	Square....													7.5			781.6
	..do....	Hexagonal													6.5		3.7	780.6
	Square..	Square....													7.5			781.7
	..do....	Hexagonal													6.5		3.8	780.7
	Button..	Square....													14.0			1,024.1
	..do....	Hexagonal													13.0		5.2	1,023.1
	Square..	Square....													14.0			1,024.9
	..do....	Hexagonal													13.0		6.0	1,023.9
	Button..	Square....													12.9			1,294.4
	..do....	Hexagonal													11.9		6.0	1,293.4
	Square..	Square....													12.9			1,296.6
	..do....	Hexagonal													11.9		8.2	1,295.6
	Button..	Square....													24.3			1,605.2
	..do....	Hexagonal													20.2		8.7	1,601.1
	Square..	Square....													24.3			1,608.2
	..do....	Hexagonal													20.2		11.7	1,604.1
	Button..	Square....													34.0			2,310.0
	..do....	Hexagonal													28.0		13.3	2,304.0
	Square..	Square....													34.0			2,316.9
	..do....	Hexagonal													28.0		20.2	2,310.9
	Button..	Square....													38.5			2,713.0
	..do....	Hexagonal													30.5		16.5	2,705.0
	Square..	Square....													38.5			2,722.2
	..do....	Hexagonal													30.5		25.7	2,714.2
	Button..	Square....													36.5			3,140.3
	..do....	Hexagonal													29.0		20.3	3,132.8
	Square..	Square....													36.5			3,152.2
	..do....	Hexagonal													29.0		32.2	3,144.7
	Button..	Square....													53.2			4,103.4
	..do....	Hexagonal													44.5		27.7	4,094.7
	Square..	Square....													53.2			4,123.5
	..do....	Hexagonal													44.5		47.8	4,114.8
	Button..	Square....													75.6			4,649.8
	..do....	Hexagonal													62.5		33.0	4,636.5
	Square..	Square....													75.6			4,674.2
	..do....	Hexagonal													62.5		57.6	4,661.1
	Button..	Square....													101.0			5,229.3
	..do....	Hexagonal													87.0		40.5	5,215.3
	Square..	Square....													101.0			5,256.6
	..do....	Hexagonal													87.0		67.8	5,242.6

WOOD PIPE IN COURSE OF CONSTRUCTION.

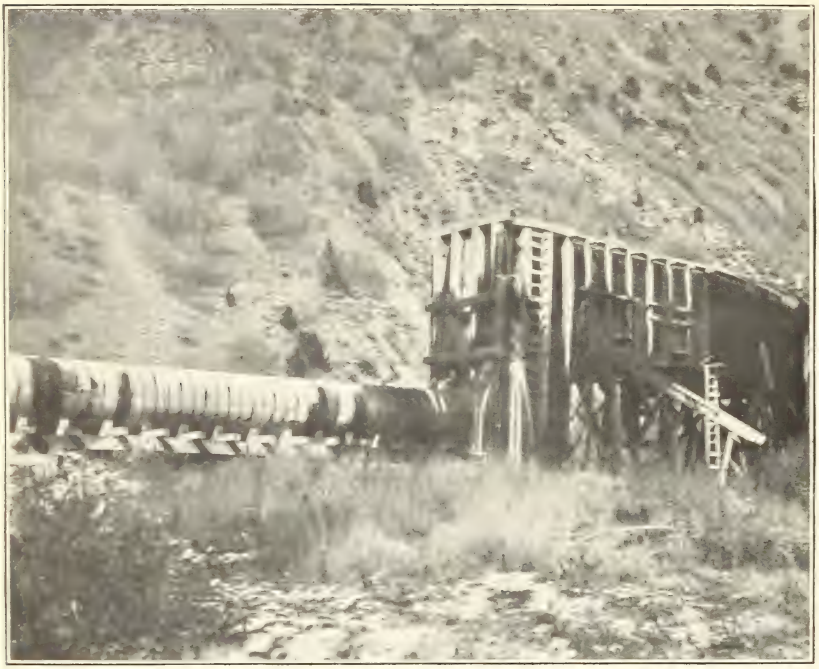

FIG. 1.—INTAKE OF PIPE-LINE AT LOGAN, UTAH.

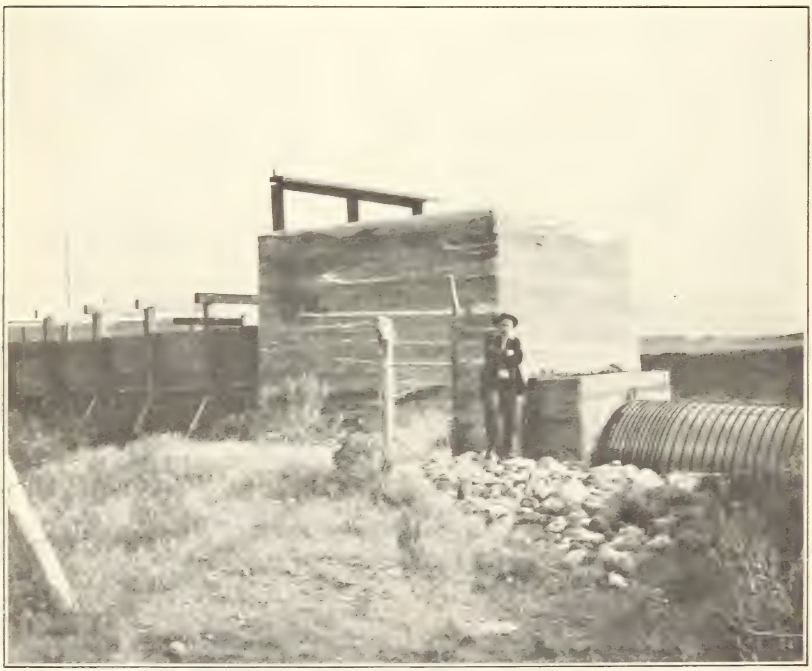

FIG. 2.—INTAKE OF PIPE-LINE CROSSING SNAKE RIVER NEAR BLISS, IDAHO.

Dimensions and weights of standard two-piece bands.

[Dimensions in inches and weights in pounds.]

Size of band.	Kind.	Threads.			Nuts.		Washers.			Heads.			Approximate length of rod required to form 1 head.	Weight per 100 plain round rods 15 feet long.	Weights.			Total weight per 100 bands 15 feet long.
		Diameter.	Length.	Per inch.	Short diameter.	Thickness.	Diameter.	Gauge No.	Hole.	Width.	Thickness.				Nuts per 200.	Washers per 200.	Heads per 200.	
	Thread each end, square nut	$\frac{7}{16}$	4	14	$\frac{7}{8}$	$\frac{1}{2}$	$1\frac{1}{4}$	14	$\frac{1}{2}$	....	....	....		578.3	16.0	4.8	.....	599.1
	Thread each end, hexagonal nut														14.0		.....	597.1
	Button head each end									$\frac{3}{4}$	$\frac{5}{16}$	$\frac{3}{4}$			.....	.....	4.7	583.0
	Square head each end									$\frac{9}{16}$	$\frac{9}{32}$	$\frac{13}{16}$			.....	.....	5.0	583.3
	Thread each end, square nut	$\frac{1}{2}$	$4\frac{1}{2}$	13	$\frac{7}{8}$	$\frac{1}{2}$	$1\frac{3}{8}$	12	$\frac{9}{16}$	....	....	....		766.5	15.0	7.7	.....	789.2
	Thread each end, hexagonal nut														13.0		.....	787.2
	Button head each end									$\frac{3}{4}$	$\frac{3}{8}$	$\frac{7}{8}$			.....	.....	7.5	774.0
	Square head each end									$\frac{21}{32}$	$\frac{5}{16}$	$\frac{7}{8}$			.....	.....	7.6	774.1
	Thread each end, square nut	$\frac{9}{16}$	5	12	$1\frac{1}{16}$	$\frac{5}{8}$	$1\frac{1}{2}$	12	$\frac{5}{8}$	....	....	....		1,000.5	28.0	8.8	.....	1,037.3
	Thread each end, heaxagonal nut														26.0		.....	1,035.3
	Button head each end									$\frac{15}{16}$	$\frac{13}{32}$	$\frac{13}{16}$			.....	.....	10.4	1,010.9
	Square head each end									$\frac{3}{4}$	$\frac{3}{8}$	$1\frac{1}{16}$			.....	.....	12.0	1,012.5
	Thread each end, square nut	$\frac{5}{8}$	5	11	$1\frac{1}{16}$	$\frac{5}{8}$	$1\frac{3}{4}$	10	$\frac{11}{16}$	....	....	....		1,257.5	25.8	15.9	.....	1,309.2
	Thread each end, hexagonal nut														23.8		.....	1,307.2
	Button head each end									1	$\frac{7}{16}$	1			.....	.....	12.1	1,279.6
	Square head each end									$\frac{27}{32}$	$\frac{13}{32}$	$1\frac{5}{32}$			.....	.....	16.4	1,283.9
	Thread each end, square nut	$\frac{11}{16}$	5	11	$1\frac{1}{4}$	$\frac{3}{4}$	$1\frac{3}{4}$	10	$\frac{3}{4}$	....	....	....		1,564.5	48.5	15.4	.....	1,628.5
	Thread each end, hexagonal nut														40.4		.....	1,620.3
	Button head each end									$1\frac{1}{16}$	$\frac{7}{16}$	1			.....	.....	17.4	1,581.9
	Square head each end									$1\frac{5}{16}$	$\frac{15}{32}$	$1\frac{11}{32}$			.....	.....	23.4	1,587.9
	Thread each end, square nut	$\frac{13}{16}$	5	10	$1\frac{3}{8}$	$\frac{7}{8}$	2	10	$\frac{7}{8}$	....	....	....		2,253.0	68.0	19.4	.....	2,340.4
	Thread each end, hexagonal nut														56.0		.....	2,328.4
	Button head each end									$1\frac{3}{16}$	$\frac{1}{2}$	$1\frac{1}{16}$			.....	.....	26.6	2,279.6
	Square head each end									$1\frac{1}{8}$	$\frac{9}{16}$	$1\frac{5}{8}$			.....	.....	40.3	2,293.3
	Thread each end, square nut	$\frac{7}{8}$	5	9	$1\frac{7}{16}$	$\frac{7}{8}$	$2\frac{1}{4}$	9	$\frac{15}{16}$	....	....	....		2,644.5	77.0	26.9	.....	2,748.4
	Thread each end, hexagonal nut														61.0		.....	2,732.4
	Button head each end									$1\frac{3}{8}$	$\frac{9}{16}$	$1\frac{1}{8}$			.....	.....	33.0	2,677.5
	Square head each end									$1\frac{7}{32}$	$\frac{39}{64}$	$1\frac{3}{4}$			.....	.....	51.4	2,695.9
	Thread each end, square nut	$\frac{15}{16}$	5	9	$1\frac{7}{16}$	$\frac{7}{8}$	$2\frac{1}{4}$	91		....	....	....		3,066.0	73.0	35.0	.....	3,174.0
	Thread each end, hexagonal nut														58.0		.....	3,159.0
	Button head each end									$1\frac{1}{2}$	$\frac{5}{8}$	$1\frac{5}{16}$			.....	.....	40.5	3,106.5
	Square head each end									$1\frac{5}{16}$	$\frac{21}{32}$	$1\frac{7}{8}$			.....	.....	64.4	3,130.4

Dimensions and weights of standard two-piece bands—Continued.

[Dimensions in inches and weights in pounds.]

Size of band.	Kind.	Threads.			Nuts.		Washers.			Heads.			Weight per 100 plain round rods 15 feet long.	Weights.			Total weight per 100 bands 15 feet long.
		Diameter.	Length.	Per inch.	Short diameter.	Thickness.	Diameter.	Gauge No.	Hole.	Width.	Thickness.	Approximate length of rod required to form 1 head.		Nuts per 200.	Washers per 200.	Heads per 200.	
1 1/16	Thread each end, square nut	1 1/16	5	8	1 5/8	1	2 1/2	9	1 1/8				4,005.0	106.3	35.0		4,146.3
	Thread each end, hexagonal nut													89.0			4,129.0
	Button head each end									1 5/16	11/16	1 1/4				55.4	4,060.4
	Square head each end									1 1/2	3/4	2 5/32				95.6	4,100.6
1 1/8	Thread each end, square nut	1 1/8	5	7	1 1/16	1 1/8	2 3/4	7	1 5/16				4,521.0	151.1	40.0		4,712.1
	Thread each end, hexagonal nut													124.9			4,685.9
	Button head each end									1 1/16	3/4	1 5/16				66.0	4,587.0
	Square head each end									1 3/16	13/16	2 5/16				115.2	4,636.2
1 1/8	Thread each end, square nut	1 3/16	5	7	2	1 1/4	2 3/4	7	1 1/4				5,068.5	202.1	38.6		5,309.1
	Thread each end, hexagonal nut													174.0			5,281.1
	Button head each end									1 3/4	1 3/16	1 7/16				81.0	5,149.5
	Square head each end									1 11/16	27/32	2 1/32				135.5	5,204.0

For determining the spacing of bands many formulas have been developed and diagrams have also been prepared for graphical determination.[1] The following formula prepared by S. Fortier has been very commonly used:

$d=\frac{S}{CPR}$ in which d equals distance between bands in inches.

S=maximum tensile strength of each band in pounds.

P=pressure of water in pounds per square inch in bottom of pipe.

R=internal radius of pipe in inches.

C=coefficient to allow for strain caused by swelling of wood, and includes safety factor of about 4 or 5 for bands.

The spacing of bands on some of the earlier pipes built was as wide as 16 inches or more, but at present 10 inches is considered the maximum permissible, and on some important recent work the maximum was placed much lower than this, even though the pressures did not require it.

There is a tendency for the ends of staves to spring out when subjected to high pressure and often under light heads where bands are farther apart, if the pipe is exposed to the sun. In order to over-

[1] Engin. News, 60 (1908), p. 343.

come this tendency it is now a common practice to specify additional bands at the joints, and to bring all joints within a space of 2 to 4 feet.

COUPLING SHOES.

The designing of shoes is now left principally to the manufacturers, and selection may be made from a number of patterns. Light weight in most instances, where not subject to excessive corrosion, is the chief consideration after strength equal to that of the bands is assured. Cast-iron shoes were used principally during the earlier years of continuous stave pipe building. They were heavy and easily broken, and on this account common cast iron has given place to malleable cast iron and steel. Malleable iron for this purpose should be of the most tenacious character, capable of standing considerable hammering without fracture. The tensile strength should be not less than 40,000 pounds per square inch of section. Steel for shoes should in quality be equal in all respects to that required for bands.

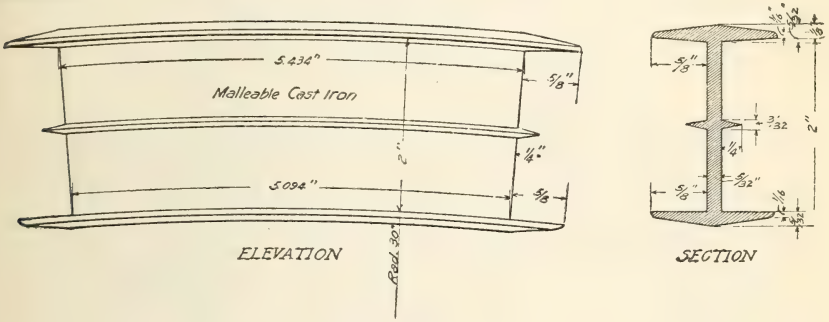

FIG. 1.—Kelsey joint.

JOINTS.

In designing butt joints, the use of thin steel clips inserted in saw kerfs is almost universal. Some variations from this form of joint have been tried, however. In the "Dwelle" pipe staves were tongued and grooved at the ends. In the "Wheeler" pipe a loose oak tongue was used instead of a steel clip, and on a pipe at Victor, Colo., clips of papier-mâché were used. None of these proved satisfactory. Another joint, known as the "Kelsey butt joint," is notably different from the usual type. This was used on pipe lines of Provo City, the Spanish Fork waterworks, and others in Utah, designed by F. C. Kelsey a number of years ago, and on the Blacksmith Fork pipe line built in the northern part of the State in 1912. This joint (fig. 1) consists of a malleable casting which takes the place of the metal clips and also fits tightly over the ends of the abutting staves. It is very highly recommended by engineers who have tried it, and appears to possess considerable merit. The cost is somewhat

more than that of the thin metal clips, but it is claimed that the difference in cost is more than offset by the time saved in building the pipe and by eliminating expense of saw kerfs.

For the ordinary clips No. 12 gauge steel or wrought iron is used. As a rule they are 1½ inches wide and the length is one-eighth inch greater than that of the saw kerf, so as to allow the ends to project one-sixteenth inch at each edge of the stave.

PROTECTIVE COATING OF BANDS.

The bands of continuous stave pipe are nearly always dipped or painted with some form of protective coating, and sometimes the shoes also. For this purpose there are numerous patented or trade preparations on the market, some one of which may be specified. They consist usually of asphaltum in combination with linseed oil or other ingredients for tempering and reducing, and, as a rule, are to be applied hot. Some manufacturers, however, are coming to recommend a cold dip instead of the hot, believing it to be equally effective.

INTAKES AND OUTLETS OF PIPE LINES.

The design of the intake and outlet of every pipe line must be a matter depending upon local conditions and character of service for which the pipe is intended. For this reason standard designs can not have a wide range of adaptability, but some points that usually require consideration in designing such structures for service of whatever nature are common enough to merit brief discussion.

The material used for intakes and outlets is usually either wood, concrete, or masonry. Wood has been used extensively and in first cost is usually cheaper than other materials. Its life is comparatively short, and if economic conditions will permit, something more durable should be employed. In connection with power developments, wells of cribwork have often been used to give the desired entrance head, and the same kind of construction is sometimes employed at outlets also. Examples of wood and concrete intakes are shown in Plate II. Figure 1 shows the intake to the pipe of the Logan (Utah) City Power Co. and figure 2 the intake of the pipe line of the Kings Hill irrigation project crossing the Snake River near Bliss, Idaho.

The plans of a wooden intake and an outlet box, fairly typical of this class of irrigation structures, are shown in a previous bulletin.[1] These were built in 1894, and after nine years of satisfactory service were still in use, though to some extent decayed. Lumber at the time these were built cost $15 per thousand delivered along the canal.

[1] U. S. Dept. Agr., Office Expt. Stas. Bul. 131, p. 49.

Due to general advance in the price of lumber in late years and the reduction in the cost of cement, concrete has come to be the material principally used for structures of this kind.

For municipal water supplies, intakes may require elaborate controlling works, including settling chambers, sand gates, etc., and in some localities steam pipes for heating the receiving chamber are provided as a precaution against freezing.[1] But ordinarily for irrigation or power lines such structures need not be elaborate or expensive. An example of this type of construction is shown in figure 2, the intake of a 72-inch inverted siphon on the Kings Hill irrigation project, Idaho. Another example in which the water enters the pipe

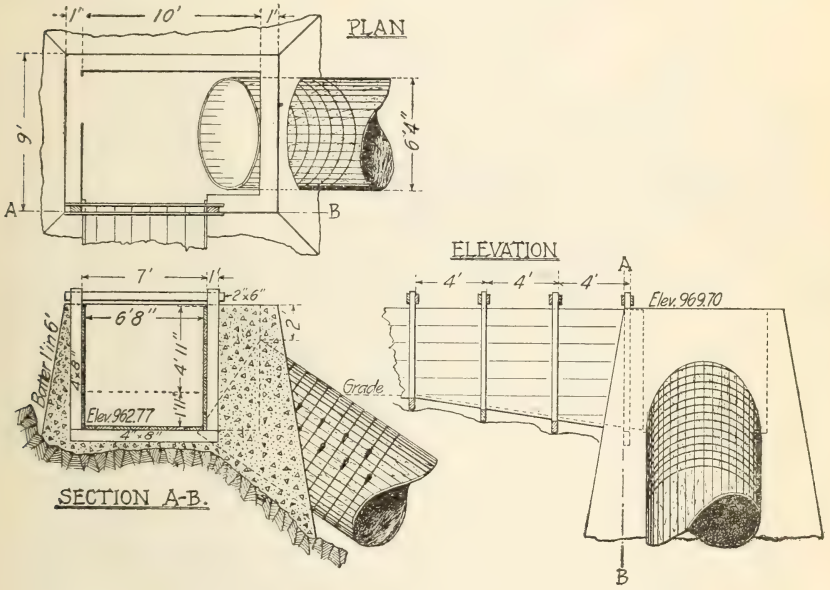

FIG. 2.—Intake of 72-inch pipe on King Hill project.

from an earth ditch instead of from a flume is illustrated by figure 3, intake of Poisin Basin siphon, Kings Hill project, Idaho. In the foregoing examples the concrete was poured around the pipe so as to form a tight connection, and the portions so incased were given additional bands. In some instances a section of cast iron or steel pipe is set in the concrete and a junction is made between that and the wood pipe. In other instances where the concrete and wood are joined, space for calking is provided by making the opening through the concrete slightly larger than the external diameter of the pipe. Either of the alternatives from the first plan given makes it possible to replace or repair the end of the wood pipe with greater facility, though the calked joint may be more difficult to keep water-tight.

[1] Engin. Rec., 66 (1912), p. 425. Intake of Denver Union waterworks.

On most irrigation systems the head of water carried fluctuates more or less and, as a rule, is far below normal for a considerable period in the spring and again for a time in the fall. At such times siphons and pipe lines may not run full. This condition may be unfavorable to their life and, as a precaution against it, gates have in a few instances been placed at the outlets as a means of throttling the discharge so as to keep the pipe full at all times. Such provision was made at the outlet of the 84-inch pipe line of the Pueblo Rocky Ford Irrigation Co., and the same practice might be followed to advantage in many other places.

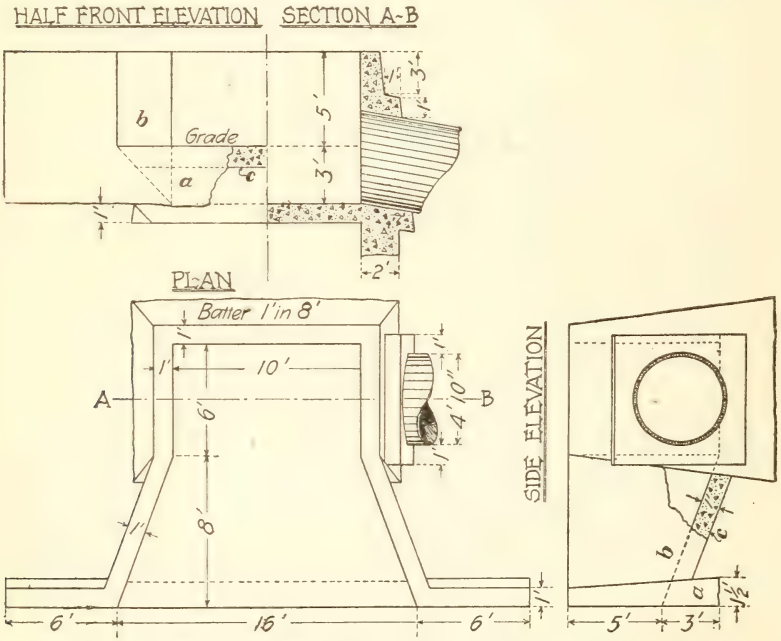

FIG. 3.—Intake of "Poison Basin" siphon, King Hill project, Idaho.

To prevent weeds or coarse débris of any kind from entering pipe lines, gratings are usually provided at intakes. However, unless carefully watched, the accumulation of weeds at the grating is liable to obstruct the entrance so as to cause the water to overflow canal banks. The danger of this, and of the serious damage which might result in many instances, have led to the removal of gratings which could not be inspected frequently. For irrigation service, where water is not carried during the winter, iron gratings are very satisfactory, but in places where ice is troublesome wooden gratings are considered better, particularly if they project above the water, for the reason that ice does not form on the wood so readily.

SPILLWAYS.

As a precaution against damage that might result from accidental stoppage of the pipe and to facilitate quick emptying in case of accident, spillways should be provided near the intake to siphons on irrigation systems where it is feasible to do so.

AIR VALVES.

At every summit of a wood-pipe line, an air valve or chimney should be placed. This is to allow air to enter so as to prevent a vacuum and liability of collapse when the pipe is emptied, as well as to permit the escape of air that may accumulate at such points. Of the various types of air valves on the market one in common use is illustrated by figure 4. A valve of this kind remains open until closed by internal water pressure, and by means of an angle valve air that accumulates while the pipe is in service may be released by hand.[1] Where practicable, iron pipes open at the top are carried to a point above the hydraulic gradient in preference to the use of air valves at summits. Air valves and chimneys are usually connected to wood pipe by means of cast saddles, which are held in place by steel bands (Pl. III, fig. 1).

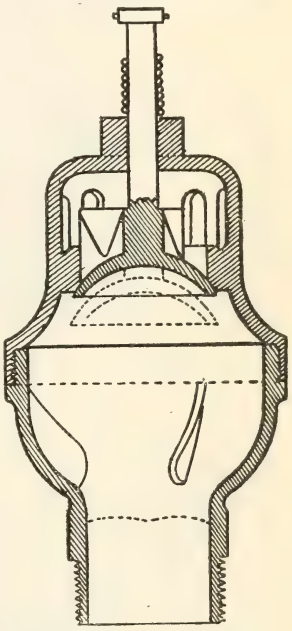

FIG. 4.—A type of air valve. (Patented.)

BLOW-OFFS.

Blow-offs are attached near the bottom at low points of the wood pipes in a manner similar to that of attaching chimneys, and a sufficient number should be provided so that every section of the pipe line may be drained and flushed out. Ordinary gate valves are usually employed for this purpose, the size to use being dependent on conditions. In lines where a large amount of silt is liable to accumulate, such valves should be of large size.

On the 84-inch pipe of the Pueblo, Rocky Ford Irrigation Co. the 6-inch blow-offs operating under a head of 75 feet would completely clog up with grass, leaves, and débris. To clean the pipe it was necessary to cut a number of holes through it. These were made 30 inches square. New blow-off gates of this size were designed to replace the 6-inch ones originally used.

[1] For other designs of air valves see Jour. New England Water Works Assoc., 8 (1893–94), p. 27; Engin. News, 33 (1895), p. 234; Trans. Amer. Soc. Civ. Engin., 36 (1896), p. 23.

The experience with 6-inch blow-offs on the Kings Hill pipes was similar. Silt in the nipples became so compact that water could not be forced through, and small holes were bored through the pipe to drain it. Then the valves were removed and cleaned. Flushing the valves occasionally would perhaps obviate this trouble. Where the water carries extraordinary quantities of sand or silt it may be advisable to provide sand boxes near the intakes. This was done on the Santa Ana Canal in California,[1] the lower Yakima Irrigation Co.'s canal in Washington, and on other canals.

On the 31-inch siphon at Prosser, Wash., a 12-inch valve was used. (Sunnyside Canal, U. S. Reclamation Service.)

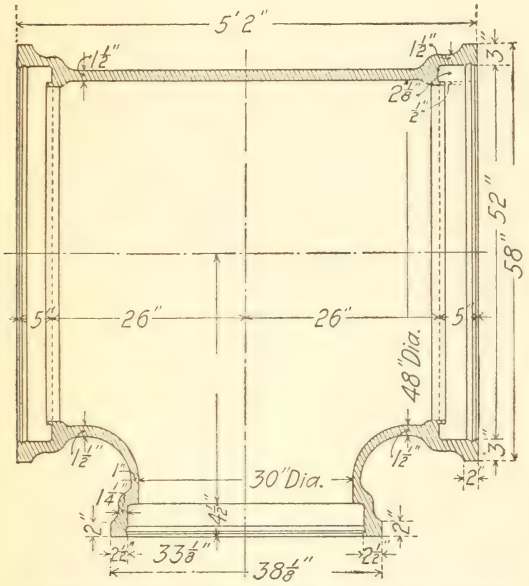

FIG. 5.—Forty-eight-inch special tee for joining wood pipe to cast-iron pipe.

Where pipes are kept full during the winter, air valves and blow-off gates should be protected against freezing.

CONNECTIONS WITH OTHER KINDS OF PIPE.

On the Sunnyside Canal in Washington the portions of the Mabton and Prosser siphons at intake and outlet ends where the pressures are light are made of concrete pipe. These are joined to continuous stave wood pipes which sustain the greater pressures. In other pipe lines wood is used for heads up to approximately 200 feet, and steel or cast iron for greater pressures. Again, where curves too sharp for the wood pipe are required, in passing under railroads and in other situations, it is frequently found necessary to join continuous stave pipe to that of some other type.

A common practice in joining wood and cast iron or steel is illustrated by Plate III, figure 2. The wood pipe is made to overlap the metal pipe, and by means of the bands is cinched up to make a tight joint. The usual lap is 12 to 18 inches, but laps of as much as 4 feet have been made.

A connection of this kind is criticized on the ground that it does not permit proper saturation of the wood pipe where it overlaps the

[1] Trans. Amer. Soc. Civ. Engin., 33 (1895), p. 129.

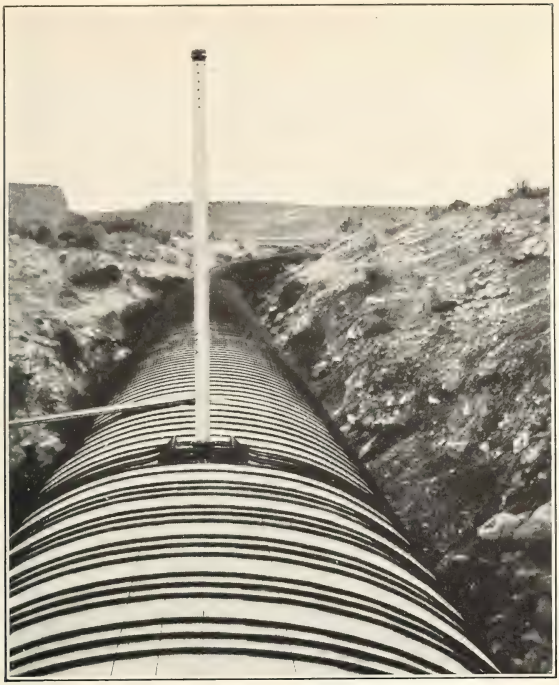

FIG. 1.—CHIMNEY ATTACHED TO WOOD PIPE.

FIG. 2.—UNION OF WOOD AND STEEL PIPE.

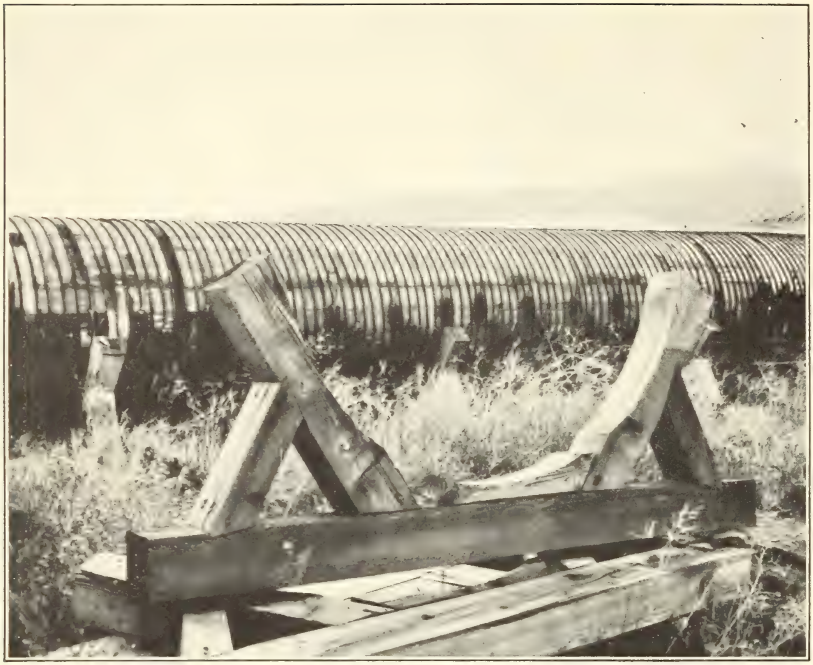

FIG. 1.—CRADLES USED TO SUPPORT WOOD PIPE, KING HILL PROJECT, IDAHO.

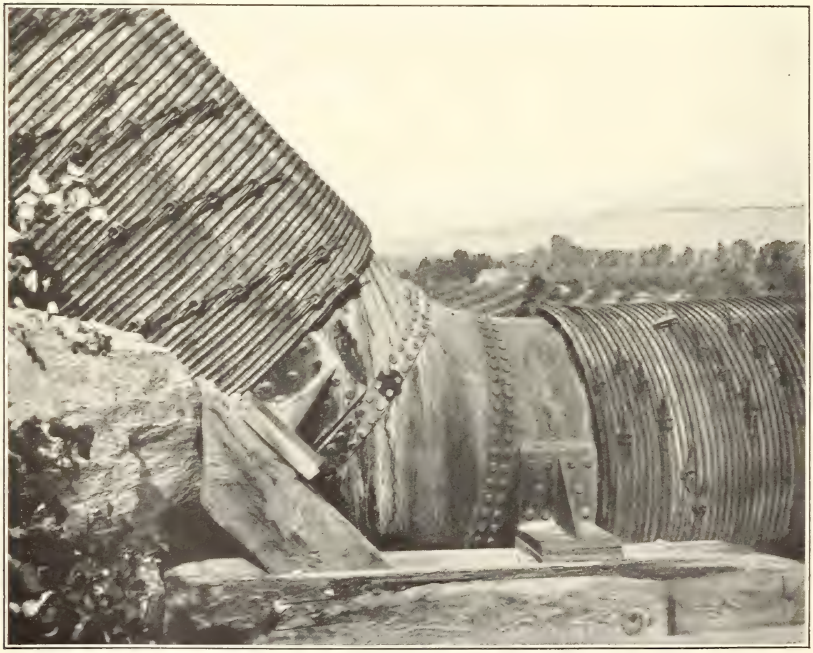

FIG. 2.—STEEL ANGLE IN 44-INCH PIPE, SHOWING METHOD OF JOINING WOOD AND STEEL AND METHOD OF ANCHORING PIPE ON STEEP SLOPE.

metal, thus leaving it subject to decay. It is considered better practice to insert the wood pipe into the metal pipe and calk with lead and oakum. To do this usually requires a special coupling either of cast iron or steel. An example of a cast fitting illustrating this method of joining wood pipe and cast-iron pipe is shown by figure 5, and another of steel for uniting wood pipe and steel pipe by figure 6. An important feature in both of these designs is the thimble or flange which fits inside the wood staves to prevent them from being forced in by the calking.

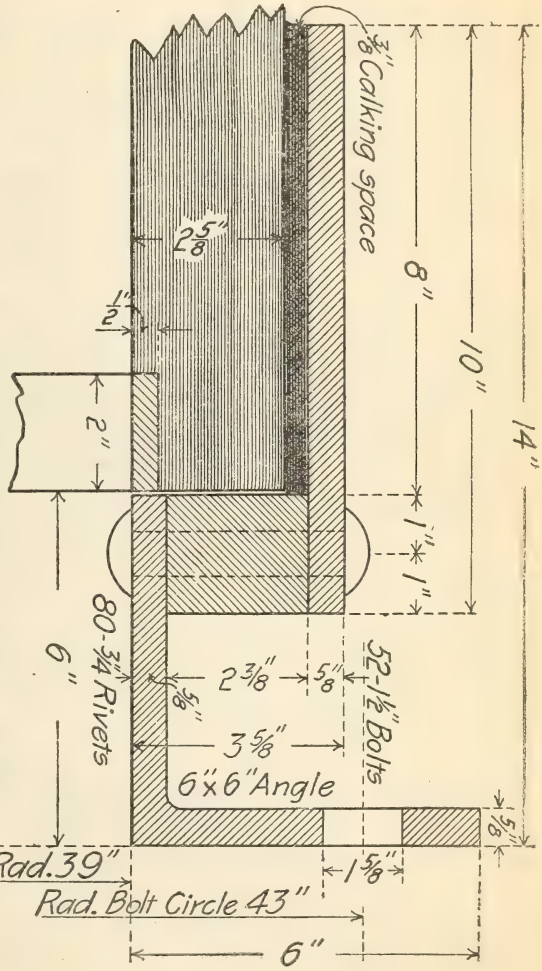

FIG. 6.—Riveted steel bell for connecting wood pipe to steel pipe.

CRADLES.

If continuous stave pipes are built above ground it is usually best to support them in "cradles" or "chairs." In the design and spacing of supports of this kind the ideas and judgment of engineers differ and as yet there is no standard practice.

Cradles of the general type shown by figure 7, A, were used on several large pipe lines of the Kings Hill irrigation system in Idaho, and they appear to be well designed. On some pipe lines the 2 by 12 inch mudsills are continuous; on others, blocks 18 inches long are used. The use of short blocks in this way is more economical of material, and requires less grading. The cradles of the type shown by Plate IV, figure 1, were spaced 6 feet center to center under a 54-inch pipe, and to support a pipe 100 inches in diameter cradles of the same type of 8 by 8 inch material

were used with 6-foot spacing. Supports similar to the other cradle shown (fig. 7, B) have been used on a number of pipe lines. The Logan (Utah) city power pipe line rests on such cradles spaced 4 feet center to center, with no mudsill blocks beneath the 6 by 6 inch

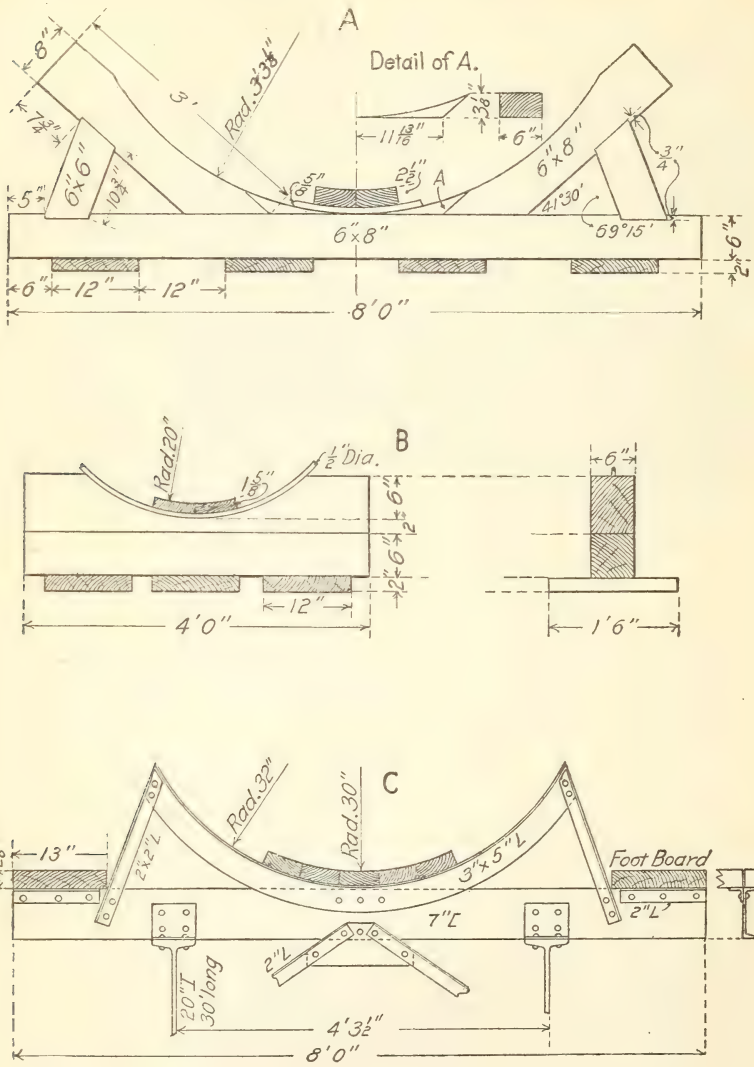

FIG. 7.—Cradles for carrying stave pipe.

timber. The 48-inch pipe of the Portland Flouring Mills Co., at Dayton, Wash., is carried on cradles 12 feet apart, and while this spacing is unusually wide the support appears to be ample.

Some large wood-pipe lines carried across rivers and ravines on bridges, or trestles of steel, are supported by cradles also of steel.

The Snake River crossing of the Kings Hill project, near Bliss, Idaho, and the new trestles of the Denver Union Water Co., afford good examples of such cradles (fig. 7, C).

The 84-inch pipe of the Pueblo, Rocky Ford Irrigation Co. is in places supported on rock cradles set about 15 feet apart.

ANCHORING PIPES.

In order to secure surface pipes against water thrust at sharp horizontal curves, and to guard against the tendency to creep on steep inclines, anchorage in some manner is sometimes necessary. One method of anchoring a 44-inch pipe, as well as the way of designing an angle too sharp for the curvature of wood pipe, is illustrated by Plate IV, figure 2. Another method is to build around the pipe a pier or mass of concrete or masonry to serve as anchorage.

LOCATION OF CONTINUOUS STAVE PIPE LINES.

The location of a pressure pipe line is very often a simple matter, particularly where the distance traversed is short, but in the case of long lines of wood pipe a proper and satisfactory location may involve a number of important considerations. This is particularly true if the line is to traverse a rough, mountainous region. Many such pipe lines have been built without due knowledge or appreciation of the importance of certain factors, and failures or unsatisfactory service may frequently result from faulty location.

As a rule, a pipe line must follow more or less closely the variations of the ground surface, but in both plan and profile sharp curves should be avoided as much as possible. The introduction of sharp curves tends to increase the cost and difficulty of construction as well as of maintenance and repairs and to decrease the carrying capacity. Horizontal and vertical curves should not be placed in the same section of pipe, and a tangent between curves is always desirable. The degree of curvature permissible depends largely on the diameter of the pipe and upon the thickness and kind of staves. A radius of 60 times the diameter of the pipe is usually taken as a measure of allowable curvature, though sharper curves are not uncommon.

A wooden pipe should be located so as to be under all conditions entirely below the hydraulic gradient, and in making extensions, or in taking off branches at any time from a line already established, care should be taken not to lower the hydraulic gradient so as to leave the original pipe above it. Carelessness with reference to these considerations has in some instances been the cause of serious damage and expense.

On the point as to what the minimum distance below the hydraulic gradient should be, engineers differ in opinion. Assuming that pressure sufficient to keep the staves well saturated is necessary to pre-

vent decay, some engineers advocate 50 feet as the minimum so far as it is possible to secure such location, while others place it at 25 feet. With reference to the relation of pressure to durability of the wood, much may depend on other conditions of the location, particularly as to whether or not the pipe is placed in contact with the soil. If the pipe is placed in the ground or in contact with the soil, a pressure head of 50 feet or more is preferable to anything less, but if it is kept free from contact with the soil, 15 feet below the hydraulic gradient is as good as 50. By locating the pipe close to the hydraulic gradient fewer bands are required, but nothing is saved in keeping the pressure lower than 20 feet of head.

Evidence based on the experience of the past 20 years appears to be sufficient to show that, in general, continuous stave pipe lines should be located above ground and free from all contact with it, though opinions diametrically opposite with reference to this point have prevailed and still prevail. By those who favor locating pipes in the ground, it is argued that they are thus better protected from injury from fire, freezing, falling rocks, falling trees, landslides, etc., and that the life of the wood will be prolonged. In answer to which it may be claimed that a pipe line properly patrolled and maintained is seldom in serious danger from fire; the velocities as a rule are a sufficient safeguard against freezing in most places where such pipes are used, though wood pipes, even if frozen, may be easily repaired; in a region so rough that danger from landslides or falling rocks is a matter for consideration, the cost of excavating a trench is usually very great and material suitable for backfilling difficult or impossible to obtain, so that other means of protecting the pipe from such injury may be much more economical; and while under ideal conditions as to character of soil, depth of covering, pressure, etc., the life of a pipe in the ground might be longer than that of one fully exposed, experience shows conclusively that in practice there is great uncertainty as to conditions; that they are seldom ideal in all respects, and that burying has shortened the life of many pipes, both by decay of wood and by corrosion of bands. The conditions of a pipe above ground may be easily determined at any time, and if repairs are required they can be made with much less difficulty and expense than would otherwise be possible. If, however, reasons appear sufficient to justify placing a pipe in the ground, as they may in some instances, it is best to insure a deep covering of a nature that will most nearly exclude air from the pipe, particularly if the water pressure is light. Gravel, shell rock, or other porous material is not satisfactory for backfilling.

Summits and depressions in the line should be avoided as far as consistent with economical location. Where water courses are to be

crossed it is usually best to carry the pipe line over the stream rather than under it. This facilitates draining the pipe, and repairs can be more easily made.

CONSTRUCTION OF CONTINUOUS STAVE PIPE.

Where the pipe is to be built in a trench, the excavation is made from 1 to 2 feet wider than the diameter of the pipe. Then the staves of the lower half of the pipe are set up in a U-shaped form made usually of 1½-inch gas pipe bent on a curve equal to the outside diameter of the pipe. Another piece of gas pipe bent into a circle, of diameter slightly less than that of the wood pipe, with the ends overlapped and spread so that it will stand alone, is set on the lower staves already placed, and serves as a form for the upper part. If wooden cradles are used and two-piece bands, the lower section of the band, set in a cradle, is sometimes used as the bottom form instead of the gas pipe. A few bands sufficient to hold the staves in place are then slipped on, and the final banding is completed by other men, the spacing of each section being marked along the pipe according to tables or profiles in the hands of the foreman. During the progress of lining up and partially tightening the bands, the pipe is rounded out evenly and the staves are driven up to make the butt joints tight. Wooden mallets are used for the "coopering," and in driving home the staves iron-bound hardwood blocks are used with sledge hammers.

The end driving must usually be done repeatedly as the bands are tightened, care being exercised not to bruise or injure the staves. The final cinching may be delayed somewhat and should be done with careful judgment, particularly where the spacing is close, in order to avoid crushing the wood or shearing quarter-sawed staves. Special braces or wrenches with long shanks and short leverage are generally used for this work, each builder, as a rule, designing his own tools. Curves are made by crowding or pulling the partially banded pipe to the desired position with jackscrews or blocks and tackle.

A pipe-laying gang usually consists of from 8 to 16 men, the number depending on the closeness of banding, etc. The speed of construction depends upon the size of the pipe, spacing of bands, curvature, etc. On a 48-inch pipe built at Clarkston, Wash., in 1906, 250 feet was the most that was laid in 10 hours, and the amount ran down to as low as 50 feet where work was difficult.

According to J. D. Schuyler,[1] 150 to 300 feet of 34-inch pipe was made per day by a crew at Denver, Colo., the number of bands placed ranging from 700 to 1,000, while on 44-inch pipe 500 bands were placed per day. In 1910 a 48-inch pipe, 10 miles long under a

[1] Trans. Amer. Soc. Civ. Engin., 31 (1894), p. 135.

maximum head of 130 feet, was built for the Denver Union Water Co. The contracting firm states that this was done in 75 days, with a force consisting of 150 men and 100 teams, and that this included hauling 30,000 tons of material an average of 10 miles on wagons. This is considered to be very rapid construction for a pipe of this size laid in a trench averaging 7 feet deep.

In building a long line of continuous stave pipe it is customary to employ several crews at convenient intervals of a thousand feet or more. The different sections of pipe so built are joined by cutting staves to fit, allowing about one-eighth-inch extra length so that when sprung in place the end joints come tight.

COST OF CONTINUOUS STAVE PIPE.

The cost of continuous stave pipe of any particular size varies so much according to design, spacing of bands, location relative to transportation lines, conditions affecting erection, etc., that it is impossible to give general costs, but some data of a specific nature relative to certain pipe lines which have been built may be of value for purposes of comparison.

Eighteen-inch.—At Astoria, Oreg., 7½ miles of 18-inch pipe built in 1895.[1] Staves, fir, 1⅜ inches thick, milled from 2 by 6 inch lumber. Bands, seven-sixteenths inch diameter upset to one-half inch at threads. Clips No. 12, B. W. G., 1½ inches wide, treated. Shoes, Allen patent, malleable iron, weight 10 ounces each. Contract prices of steel in bands, 4.8 cents per pound. Lumber, gross measurement, $35.40 per 1,000 feet b. m. Average spacing of bands, 5 15/16 inches. Cost of pipe to the city, 90.33 cents per linear foot, including accessories or 76 cents excluding them. These figures are not the actual cost of building the pipe, as Mr. Adams says: "It is presumable that the contract prices represent a profit of from 12½ to 15 per cent." The approximate cost of replacing this line with one of the same size and length in 1911 was $75,000, redwood staves 1½ inches thick being used in the new pipe. The cost given includes engineering expense.

Thirty inch.—At Denver, Colo., in 1889,[2] a 30-inch pipe 16.4 miles long required 1,869,000 feet b. m. of Texas pine, which cost $51,399.28, at $27.50 per M, and 271,900 half-inch bands, which cost $54,299.55; erection of pipe by contract, at 5.1 cents per band, $13,866.03; total, $119,564.86, or $1.36½ per linear foot. Trenching cost 48.3 cents per foot in addition to foregoing.

At Jerome, Idaho, 1912, 1,529 feet; 30 inches diameter; fir staves, 1⅝ inches thick; bands, one-half inch diameter; pressure, 0 to 47 feet; average haul, 10 miles; built in trench and buried 2 feet deep. Cost, including everything except engineering and administration, $2,922, or $1.91 per linear foot.

At Idaho Falls, Idaho, 1905; 800 feet; 30 inches diameter; fir, one-half inch bands; maximum head, 34 feet; supported on wood cradles. Cost, $1.55 per linear foot, including everything.

At Kennewick, Wash., 1908; 9,490 feet; 30 inches diameter; head, 0 to 180 feet; built by contract on prepared foundation for $1.85 per foot. Includes delivery of material at railroad point, but no haul or earthwork.

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[1] Trans. Amer. Soc. Civ. Engin., 36 (1896), p. 1.
[2] Trans. Amer. Soc. Civ. Engin., 31 (1894), p. 143.

Thirty-two inch.—At North Yakima, Wash., 1894; Redwood siphon 940 feet long; 32 inches diameter; maximum head, 90 feet; bands, one-half inch diameter; built by force account for $2,500, equals $2.66 per linear foot. Duplicated by contract, 1903, for same figure.

At Filer, Idaho, 1901; 1,300 feet; 32 inches diameter; fir staves, 1⅝ inches thick, at $40 per thousand feet b. m. on basis of 2 by 6 inch lumber; bands, one-half inch diameter, 57 cents each; malleable iron shoes, 4 cents each; tongues, ⅛ by 1½ by 5 7/16 inches, 3 cents; pressure head, 0 to 40 feet; work done by force account; wages, $2.50 for 10 hours, and foreman $5; hauling material 8 miles, $75; erecting on top of ground, approximately $250. Cost of staves and steel laid down at Filer, $1.35 per foot of pipe; haul and erecting, 25 cents; total approximately, $1.60 per foot.

Thirty-six inch.—At Jerome, Idaho, 1912; 650 feet; 36 inches diameter; head, 0 to 43 feet; staves, fir, 1⅝ inches thick; band, one-half inch diameter; built in trench and buried 2 feet deep; average haul, 4 to 5 miles. Cost, including everything except engineering and administration, $1,596, or $2.46 per foot.

Forty inch.—At Jerome, Idaho, 1912; 3,113 feet; 40 inches diameter; head, 0 to 100 feet; fir staves, 1⅝ inches thick; bands, one-half inch diameter; built in trench and buried 2 feet deep; average haul, 10 miles; cost, $8,933, or $2.87 per foot, including everything except engineering and administration.

Forty-two inch.—At Jerome, Idaho, 1912; 980 feet; 42 inches diameter; head, 0 to 51 feet; staves, fir, 1⅝ inches thick; bands, one-half inch diameter; built in trench and buried 2 feet deep; average haul, 4 to 5 miles; cost, $2,556, or $2.61 per foot, including everything except engineering and administration.

Forty-four inch.—At Wenatchee, Wash., 1902–3; 9,000 feet; 44 inches diameter; maximum head, 235 feet; bands, one-half inch diameter; fir staves, 1⅝ inches thick; laid in trench, and on bridge across Wenatchee River; contract price for pipe, $2.20 per linear foot. Excavating and backfilling not included.

At Palisades, Colo., 1909–10; 3 fir pipes, 44 inches diameter; 2,850 feet; 1,055 and 1,150 feet in length; cost by contract, $3.15, $3.25, and $2.90 per linear foot, respectively. No earthwork included.

Forty-eight inch.—At Palisades (orchard mesa), Colo., 1909–10; for 6 pipes 48 inches in diameter and varying lengths and heads, the unit prices ranged from $2.40 per foot up to $4.75 per foot, the average of the six being $3.52; material, fir.

At Deer Park, Wash. (about 1909), 94,000 feet of fir pipe; head, 0 to 70 feet, built in trench; contract price, $2.35 per foot, includes delivery of all material at railroad point and erection of pipe, but no haul or earthwork.

Forty-eight inch.—At Clarkston, Wash., 1906; fir staves, 1⅝ inches thick, ½-inch bands; built in trench by force account, for light head; cost, $2.25 per foot, no earthwork included. Foreman received $3.50 per day and other men $2.50 for 10 hours.

Fifty-eight inch.—At Pueblo, Colo., 1907; 2,277.5 feet; cost by contract, $6.14 per foot, no earthwork included.

Sixty inch.—At Pueblo, Colo., 1907; on 17 fir pipes the unit price per foot ranged from $4.19 to $6.58, averaging $5.51. The combined length of 17 pipes equals 19,821.5 feet, making the average price per foot on this basis equal $6.27; earthwork not included.

Sixty inch.—At Nissa, Oreg., 1912; 6,700 feet; average head about 65 feet; bands, ⅝ inch diameter; staves, fir, 2 by 6 inches; built on wooden cradles; contract price, $4.25 per foot, included material, erecting, and freight, but no haul or earthwork.

Eighty-four inch.—At Pueblo, Colo., 1911; 18,000 feet; maximum head, 70 feet; fir staves, 2⅝ inches thick; bands, ¾ inch diameter; maximum spacing, 10 inches; minimum, about 4 inches; contract price, $6 per linear foot, including everything except hauling and earthwork. Line very crooked, with 14 vertical curves. Much of it is about one-half in ground. Total cost of line was about $9 per foot, everything included.

Fir staves at Seattle, Wash. (December, 1912), were quoted at $30 to $32 per thousand feet b. m., according to size, etc. They take the same freight rate as lumber of the same class. Redwood staves at San Francisco were quoted at about $45 per thousand. The price of malleable iron shoes, at Marion, Ind., was approximately $3.75 per hundredweight on lots of from 1,000 pieces to a carload, with an additional charge of 10 cents per hundredweight if dipped in rust-proof paint. Drop forged steel shoes 3½ inches long were quoted at 2¾ cents to 3½ cents each at Ballard, Wash., and 5-inch shoes at 3½ cents to 4 cents each.

Bands made at Pueblo, Colo., were quoted f. o. b. Spokane, Wash., at $2.97 per hundredweight for carload lots, 10 cents per hundredweight additional being charged if required to be bent and dipped.

Steel tongues are quoted at the same prices as bands.

Pipe coating of a well-known brand used as a dip for bands was quoted at $57.50 per ton f. o. b. the Chicago factory.

MACHINE-BANDED PIPE.

Machine-banded pipe is being very extensively manufactured on the Pacific coast and at several points in the Eastern States. The principal factories of the West are at San Francisco, Cal.; Portland, Oreg.; Tacoma, Wash.; Seattle, Wash.; and Vancouver, B. C. Other factories are at Elmira, N. Y.; Bay City, Mich.; Williamsport, Pa.; and Alexandria, La.

Redwood is used for the pipe made at San Francisco, while fir is used exclusively at the other western points mentioned. The eastern factories use white pine and tamarack, principally, for water pipe, and hard maple, beech, and birch for special mining purposes. In Louisiana, water pipe is made from cypress, which wood is used also for steam-pipe casing.

The original machine-banded pipe consisted of logs turned in a lathe, machine bored, and then wound with continuous flat steel bands. Pipe of this type in sizes from 2 to 6 inches in diameter is still manufactured in Michigan, but most of the machine-banded pipe is now made up of staves, the sections ranging in length from 8 feet to 12 feet in the East, and to 20 feet in the West. Diameters run from 2 inches up to 48 inches. Western factories, however, build little pipe of this kind more than 24 inches in diameter.

The thickness of the staves varies to some extent. The redwood pipe in usual sizes is about 1 inch thick and the fir pipe 1¼ inches. The eastern pipe is usually 1⅜ inches thick, while for pressures of 40 pounds or more and in sizes from 24 inches up, the shell of some of it is made 3 inches thick.

Galvanized steel wire is used exclusively on the Pacific coast for banding. The size of the wire varies from No. 8 to No. 0, and the closeness of wrapping is regulated according to the pressures for which the pipe is designed. These may range from very low heads up to 400 feet or more. The eastern factories band their pipes with hot rolled steel 14 or 16 gauge, 1 inch wide, and No. 16 and No. 18 gauge, 1½ inches wide. The banding is done with a machine which imposes on the steel a tension sufficient to make a very tight contact with the wood, and may even indent the staves somewhat where wire is used. The ends of the bands are secured with staples or clips.

After the pipe is banded and the ends are milled for couplings, each section is dipped in a hot asphaltum preparation which thoroughly coats the bands and exterior of the pipe, then it is rolled in sawdust or shavings to form an outer covering, which renders it more agreeable to handle.

COUPLINGS.

Couplings for machine-banded pipe are of several types. Of these one of the commonest is the "inserted joint." To make this coupling a tenon is milled on one end of a section of pipe and a mortise on the other, so that the connection is made by simply inserting the tenon of one section into the mortise of another and driving together. In the western pipe this form of coupling is used principally for low pressures. Where greater strength is required reinforcement may be applied to this joint by using individual bands. For another form of coupling tenons are made on both ends of each section of pipe, and with each joint a wooden stave collar or sleeve is used, into which the tenons are inserted. These collars for small pipes are machine banded the same as the pipe, but for the larger sizes individual bands are used. Collars of riveted steel or iron were used with such pipe in the earlier days of its manufacture on the Pacific coast, and cast-iron collars have been employed also in many places. The latter material is still used for bends, crosses, tees, reducers, and other specials, but for collars it has been almost wholly supplanted by the other forms mentioned. The wooden collars are cheaper, but because they often decay quickly are much inferior to those made of iron.

USE OF MACHINE-BANDED WOOD PIPE.

Machine-banded wood pipe has had its most extensive use in the Pacific coast and Rocky Mountain States for municipal waterworks systems, where there is scarcely a city or town of any consequence

but what has at some time put in more or less of it, and the demand for this purpose continues to require a large output from the factories. It is also used a great deal in conveying water supplies for manufacturing purposes and fire protection for factories and mills, for railway tanks, for power plants, hydraulic sluicing operations, etc., and during recent years there has been a great deal of it used for irrigation purposes, particularly in the Northwestern States. In the East it is used to some extent for municipal water supplies, considerably for various purposes in the mining regions, and for oil conduits, insulated wire conduits, steam pipe casing, etc.

For municipal waterworks the low first cost of machine-banded wood pipe as compared with that of cast iron or steel pipe has in most instances been the consideration leading to its use, and many communities which now have an abundance of water for domestic purposes, fire protection, etc., would still be unsupplied had not some such cheap type of pipe been available.

While possessing some advantages other than that of low first cost, machine-banded pipe, according to the experience of many localities, has been found inferior in many respects to cast iron and steel for city mains and connections. The complaint most frequently expressed with reference to its use for this service relates to trouble arising from leaks, which occur mainly at the joints. Such leaks may develop as the result of decayed collars, from carelessness in putting the pipe together, from increasing the pressure above that for which the pipe was designed, or from other causes. While in many cases even a considerable leakage may be permissible, in others any material loss is highly objectionable. Leaks are particularly objectionable where pipes are located in paved streets, and owing to the difficulty in avoiding leaks, as well as because its life is usually shorter than that of metal, wood pipe is usually replaced before paving, and in the larger cities its use for distributing systems is now being very generally discontinued.

For service of a more or less temporary nature, such as hydraulic sluicing, dredging, etc., where absolute tightness is not essential, but where low cost, ease of transportation, facility of putting together, removing, and relaying at small expense are desirable considerations, machine-banded wood pipe is peculiarly well adapted.

The use of machine-banded wood pipe in connection with irrigation work is confined to the West, particularly the Northwest, where hundreds of miles of it have been installed for delivery pipes of small pumping plants, for inverted siphons, etc. In a number of places the entire water supply is conveyed through such pipes, delivery being made to each unit of area, often as small as 5 acres or less. And beyond this, many farmers use wood pipe instead of

head ditches or flumes, tapping it and inserting small hydrants at the head of each tree row or at closer intervals.

These hydrants usually consist of three-fourths-inch galvanized-iron pipe which is screwed into the shell of the wood pipe, and equipped with a cheap valve for regulating the discharge. The cost of such outlets, including the threaded nipples 18 inches long and the valves, is about 40 cents each.

The conditions of irrigation service are in perhaps a majority of cases unfavorable to a long life of this kind of pipe, and where the pipe is empty for several months out of the year decay is often very rapid, but except for this disadvantage no substitute has been found which meets so many of the other requirements of irrigation service.

COST OF MACHINE-BANDED WOOD PIPE.

The cost of machine-banded wood pipe varies with the head for which it is made, fluctuations in the market prices of materials, the kind of wood used, etc., and will differ also in accordance with freight or transportation charges from the factories to different points.

The following prices f. o. b. cars at Seattle, Wash., quoted for estimating purposes only, will give some idea of the present prices of fir pipe, and from the weights given the freight charges to any point may be ascertained by consulting railway rates. A minimum carload is 30,000 pounds.

Table showing prices and weights per linear foot of machine-banded wood pipe, f. o. b. cars, Seattle, Wash.

Diameter.	Head.	Price.	Weight.	Diameter.	Head.	Price.	Weight.	Diameter.	Head.	Price.	Weight.
			Pounds.				*Pounds.*				*Pounds.*
2-inch.....	50	$0.087	3.1	10-inch...	50	$0.268	13.1	18-inch...	50	$0.597	26.9
	100	.090	3.2		100	.347	14.7		100	.750	30.8
	150	.092	3.2		150	.392	15.7		150	.884	34.6
	200	.100	3.4		200	.455	17.3		200	.992	38.0
	250	.105	3.5		250	.479	18.4		250	1.266	45.6
	300	.116	3.6		300	.503	19.4		300	1.528	54.8
4-inch.....	50	.129	5.8	12-inch...	50	.322	16.8	20-inch...	50	.655	29.6
	100	.131	5.9		100	.413	18.9		100	.828	34.4
	150	.134	6.0		150	.450	19.8		150	1.033	40.0
	200	.166	6.3		200	.532	21.7		200	1.192	44.0
	250	.176	7.0		250	.618	23.8		250	1.428	52.0
	300	.189	7.3		300	.660	25.3		300	1.615	57.5
6-inch.....	50	.163	8.3	14-inch...	50	.445	21.3	22-inch...	50	.773	33.9
	100	.168	8.9		100	.550	23.0		100	.990	40.1
	150	.184	9.1		150	.629	25.3		150	1.184	45.2
	200	.226	9.6		200	.745	28.2		200	1.415	52.7
	250	.242	10.0		250	.834	29.9		250	1.710	59.8
	300	.258	10.4		300	.916	32.3		300	1.845	65.5
8-inch.....	50	.203	10.3	16-inch...	50	.547	24.7	24-inch...	50	.855	37.3
	100	.224	10.5		100	.639	26.9		100	1.075	44.0
	150	.292	12.8		150	.734	29.3		150	1.334	51.0
	200	.332	13.7		200	.871	33.4		200	1.627	59.3
	250	.366	15.6		250	.987	36.2		250	1.934	67.8
	300	.387	16.2		300	1.132	40.2		300	2.100	74.3

The cost of wood pipe is in most places materially less than that of cast iron or steel, though direct comparisons are difficult to make. At the time the waterworks were built at Astoria in 1895, Mr. Adams

estimated that the use of wood effected a saving of 43 per cent over steel pipe of similar size, No. 12 gauge, and nearly 50 per cent over one of equivalent carrying capacity. In discussing the waterworks of Denver, in 1894, J. D. Schuyler states:

> At a moderate estimate the saving effected by the Citizen's Water Co., by the use of wooden pipe for their main conduits has been no less than $1,100,000 over the cost of cast-iron pipes of equal capacity. The interest on this amount at 6 per cent would renew the mains every five or six years, or duplicate them as often as that if necessary.

S. Fortier[1] gives the bids for supplying material and laying the following pipes at Salt Lake City, Utah, in 1900: 30-inch stave pipe, $2.95 and $3.10; 30-inch cast-iron pipe $10.20 and $10.85; 30-inch riveted steel pipe, $8.65 and $9.15; 24-inch stave pipe at $2.60 and $2.55; 24-inch cast-iron pipe, $7.45 and $8.15; and 24-inch riveted steel pipe, $5.75 and $6.05.

At Spokane, Wash., the relative prices for small pipes are about as follows:[2] 6-inch wood pipe, 25 cents per linear foot; 6-inch steel pipe, 63 cents per linear foot; 6-inch cast-iron, 72 cents per linear foot.

The price per ton of cast-iron pipe at Spokane is about $43 (1913), and somewhat less at Pacific coast points.

LAYING MACHINE-BANDED WOOD PIPE.

Laying machine-banded wood pipe is a very simple operation, and as no calking of joints is required it may be done by unskilled labor. Nevertheless, much dissatisfaction in the use of pipe of this kind may result from carelessness in handling and laying.

In shipping from the humid Puget Sound region to the arid or semiarid districts east of the mountains wood pipe may shrink very materially if allowed to lie exposed to the sun and wind for any considerable time, and for this reason it should be protected from such influences so far as possible before laying. Otherwise it may be difficult to get the pipe tight after water is turned in. Care should be exercised in handling the pipe, so as to avoid bruising or in any way injuring the tenon ends. The tenons should be carefully examined as the pipe is being put together, and, in case bruises or scratches occur, the section should be turned so that the injury will be on top where it can be easily plugged if a leak should develop.

Pipes up to 4 inches in diameter may be driven together with a maul, a tampion being used to protect the end of the pipe. Pipe 6 inches in diameter and larger can best be driven with a ram which

[1] U. S. Geol. Survey, Water Supply and Irrig. Paper 43, p. 71.
[2] Ann. Rpt. Water Div., Dept. Public Utilities [Spokane, Wash.], 1911.

may be made of a heavy piece of timber about 5 feet long. The pipe is usually driven from the coupling or mortised end.

Deflections of from 2° to 6° per joint can be made with this kind of pipe, but a straight line is desirable, and crooks in either vertical or horizontal alignment should be avoided as far as possible. Where curves are necessary, short sections of pipe may be obtained for the purpose. Greater deflections can be made with small pipe than with large sizes.

The backfilling around curves should be thoroughly tamped or puddled, as a precaution against blowing out under pressure, and metal bends and plugs should also be well staked or reinforced, for the same reason.

To make best progress in laying this kind of pipe a crew of from four to eight men is required, the number depending on the size of the pipe. The amount that can be laid in a day varies with the size of the pipe, experience of the crew, and other conditions.

The Pacific Coast Pipe Co. estimates the cost of laying western pipe at from 1½ cents per foot for 4-inch to 5 cents per foot for 24-inch, exclusive of all distribution along ditch and earthwork. The Portland Wood Pipe Co. estimates the cost of laying different sizes as follows: 4-inch, 1 cent per foot; 6-inch and 8-inch, 1½ cents; 10-inch, 2 cents; 12-inch, 2½ cents, distribution and earthwork not included. P. A. Devers, manager Pasco Reclamation Co., Pasco, Wash., gives the cost of laying pipe at Pasco, as follows: For sizes from 8 inches to 14 inches in diameter the labor cost for excavation and installation varies from 8 cents to 10 cents per linear foot, according to size. Trenches for some of the larger pipes were excavated by contract at 25 cents per cubic yard. For installing several miles of 6-inch pipe, the trenching and other labor cost was about 6 cents per linear foot. The rate of wages is not given, but presumably laborers were paid from $2 to $2.50 per day of 10 hours. Trenches were probably not more than 2 feet deep, and the material excavated was mainly a sandy soil. In gravel the cost was increased 15 to 20 per cent, according to the statement of Mr. Devers.

MAINTENANCE OF WOOD-PIPE LINES.

It should not be assumed that large continuous stave pipe lines when once installed will forever after take care of themselves. Reasonably frequent inspection is advisable, and whenever leaks are found, or injuries of any nature are sustained, they should be repaired without unnecessary delay. Negligence in this respect and failure to appreciate the importance of such inspection has not only shortened the life of many pipe lines, but has in some instances greatly increased the cost of repairing. The continued impinging of a grit laden jet from a small leak has been known to sever steel

bands five-eighths of an inch in diameter, while the failure of a section of machine-banded pipe due to the wire being cut in this way is not uncommon.

Small leaks at the joints or seams of wood pipe are usually stopped with wooden wedges. In the case of leaks around the wooden couplings of machine-banded pipe, the wedges are driven into the staves of the coupling sleeve, and not between them and the pipe. If a section of machine-banded pipe or a collar fails on account of the cutting of the wire, individual bands with coupling shoes similar to those used for the large continuous stave pipe can be obtained for making repairs. An assortment of these might well be kept on hand where likely to be needed.

The repairs of a large pipe may call for considerable ingenuity and unique methods. When several five-eighths-inch bands of the 48-inch Mabton (Wash.) siphon were cut by a leak, allowing the ends of two staves to spring out and break off, a diver was employed to make the repairs. At the bottom of the Yakima River, 15 to 20 feet under water, steel plates with gaskets, one on the inside and one on the outside of the pipe, were clamped together with bolts so as to stop the leak.

Under ordinary circumstances the repair of continuous stave pipe is not difficult. The removal and replacement of staves or portions of them is a matter of frequent occurrence. It is only necessary to remove a few bands, take out the defective stave, spring another into place, and reband. If the pipe has been buried and the threads on the bands have become badly rusted, as they frequently do, any change in the position of the nut may necessitate the use of a new band, though if the body of the band is fit to be used again a new thread may be welded on. This has been done by the Butte Water Co.

Where a pipe is above ground any landslides coming in contact with it should be cleared away as a precaution against decay, particularly if it is at a point where the pipe is under light pressure. If supported in cradles, mudsills or footings should be renewed as decay progresses, in order to avoid injury to the pipe from settling. Weeds permitted to grow along an exposed pipe may, when dry, be a source of danger from fire, and on this account if for no other reason they should be kept down so far as conditions will warrant.

On many irrigation systems it is necessary to empty the wood pipes in the fall, as a precaution against damage from freezing. Where this is the case they should be kept full as late as possible, and be filled again in the spring just as soon as conditions will permit. In some instances irrigation managers close the inlets and outlets of wood pipes when emptied in the fall, so as to prevent the

circulation of air and the consequent drying of the wood during the winter.

In the operation of pipe lines, especially irrigation "siphons," conditions frequently favor the admission of air, which may very materially reduce the carrying capacity, and sometimes it is sufficient to cause pulsations or vibrations so violent as to be a menace to the life of the pipe. This difficulty is usually remedied by the introduction of air vents at the top of the pipe near the intake, carrying them back up along the pipe itself, or perhaps to one side of the line to a point above the hydraulic gradient.

The cost of maintenance in the operation of wood pipe lines varies greatly. In many instances where there has been a careful selection of materials, good construction, and favorable conditions of service, the expense of maintenance may be for many years an almost negligible amount, while again, where the above conditions do not obtain, the cost for repairs and upkeep may be considerable. It is usually less during the first few years than it is later on in the life of a pipe.

A. P. Merrill, manager of the Utah Power Co., in connection with his experience in operating a number of pipe lines aggregating 10 miles or so in length, writes as follows:

> The maintenance of pipe lines depends, of course, on the manner in which they are constructed. At this time I have no definite maintenance costs which can be given to support any statements that I might make. In general, however, I should say that a wood pipe line properly constructed with Kelsey joints and laid under sufficient pressure requires practically no maintenance, at least during the first 10 years. We have had comparatively new lines, however, where the construction was somewhat faulty in some respects, and where the butt joints were not used, which require more or less maintenance work during each year.

Eugene Carroll, manager of the Butte Water Co., in writing concerning the pipes built at Butte in 1892, 1899, and 1900, makes the following statement:[1]

> The pipe connects our reservoirs, one 13 miles and the other 22 miles out, with our reservoirs in town. The watchman, which we have to keep at each reservoir, makes a trip over the pipe line once a week. Occasionally in making these trips it is necessary to dig out the pipe for small leaks, such as worm holes on butt joints, but with two exceptions we have never had to use more than two men in repairing leaks, and have never had to shut off the water. Our two exceptions are, first, during the winter of 1893 ice formed inside of our pipe line, being caused from the fact that our reservoir was not completed, and a jam was caused inside the pipe, bursting it, requiring the shutting off of the water and about 12 hours to repair it. Last spring on our new pipe line a leak developed near one of our valve chambers, and before it was discovered and the water shut off a bad washout took place, which washed the supports away from the pipe line for about 1,000 feet, necessitating the rebuilding of the line, taking about four days to do it.

[1] Trans. Amer. Soc. Civ. Engin., 58 (1907), p. 73.

Writing again seven years later, Mr. Carroll repeats that one man on each of these lines is all the labor required, the inspections being made about once a week, and he says:

> I attribute our low cost of maintenance to the careful and frequent inspections we make of the lines.

The cost of repairs on the 12 miles of conduit at Astoria, Oreg., for 10 years after its construction is given by A. L. Adams as follows:[1]

Cost of repairs on 12 miles of conduit.

Year.	Cost.	Year.	Cost.	Year.	Cost.	Year.	Cost.	Year.	Cost.
1895	$108.58	1897	$63.67	1899	$46.10	1901	$243.18	1903	$350.18
1896	15.90	1898	65.50	1900	71.59	1902	314.03	1904	895.10

The foregoing figures include the expense of repairing the damage resulting from two landslides. Aside from this, most of the cost was charged to the 7½ miles of wood pipe. The total cost of repairing 27 perforations which occurred in the steel pipe in 1902, 1903, 1904, and 1905 was $297.

For repairing staves in 48-inch pipe near Clarkston, Wash., in January, 1912, R. A. Foster, engineer and manager, Clarkston system of Lewiston-Clarkston Improvement Co., gives the following detailed cost data:

	Cents.
Milling staves	3.04
Hauling, 182 ton-miles, at 37.09	18.24
Removing old pipe	3.24
Repairing old bands	2.43
Subdelivery of material	5.77
Laying	9.12
Replacing bands, 555, at 8.11 cents per band	12.16
Cook	3.04
Food, 71 cents per ration	13.42
Lost time of men	4.73
Lost time of team	1.92
Piling of old lumber saved	1.73
Superintendence	4.83
Cost of lumber, $28 f. o. b. Lewiston	81.20
Total	164.87

Making total cost per foot, $1.65.
Wages of men, 25 cents per hour.

[1] Trans. Amer. Soc. Civ. Engin., 58 (1907), p. 69.

For replacing 280 feet 40-inch pipe, January, 1911.

Item.	Cost.	Cents per foot.
Hauling staves, 78 ton-miles, $37.30	$29.30	10.4
Excavating and tearing down	41.00	14.4
Relaying	81.90	29.3
Superintendence	30.00	10.7
Piling old lumber	9.00	3.3
Lumber, 6.7 M., at $28	187.60	67.0
Total	378.80	135.1

DURABILITY OF WOOD PIPE AND FACTORS AFFECTING IT.

"How long will it last?" is a question asked perhaps oftener than any other in the discussion of wood pipe. It was the common question during the early years of its manufacture, and it is common to-day after the experience of more than 30 years of extensive use.

The failure of wood pipe is in general due either to decay of the wood or corrosion of the bands, though wearing out of the wood is also under certain conditions a matter upon which the life of a pipe may depend. The range of variability with reference to these points in the life of the pipes that have been built has been such as to demonstrate conclusively that how long any pipe will last can not be accurately predicted without a thorough knowledge of all the conditions involved.

Sufficient time has not yet elapsed to show the life of some of the earliest continuous stave pipes that were built, while others have endured but from 5 to 12 years. In support of the foregoing statement specific data bearing upon the durability of a number of pipe lines, several of which were inspected by the writer, are given in the following pages.

In writing of the first continuous stave pipe built in the West, at Denver, in 1884, S. Fortier states[1]—

> The pipe was laid in a portion of its length about 15 inches above the hydraulic gradient. Native pine, whose durability under unfavorable conditions is from three to five years, composed the staves, and in the portion of the line referred to the pipe was never more than two-thirds full of water. The top staves decayed rapidly. In the fall of the year (1889) the Denver Water Co. had bands loosened and the staves from the upper arc removed without shutting off the water. It was then found that the lumber was perfectly sound up to the surface of the water in the pipe, and in the next stave above on either side, whereas the remaining staves which the water could not reach by capillary attraction or otherwise were rotten.

A part of this line, lying close to the river, under conditions where both exterior and interior are kept wet, was said to be still in use in 1912.

[1]Ann. Amer. Soc. Irrig. Engin., 1892–93, p. 11.

In 1886–87 the next important pipe line of this kind was built from Cherry Creek crossing to Denver. Some of this lasted until 1907, when it was replaced by a 30-inch fir pipe. The original line consisted of about 7¾ miles in all, of 37, 30, and 24-inch pipe, the material being about two-thirds western yellow pine (*Pinus ponderosa*) and the remainder redwood.

In 1890 a 30-inch pipe was completed from the Platte Canyon to Ashland Avenue, Denver, about 21 miles; 16.4 miles of this line is wood—Texas pine and California redwood. It is still in use. In the spring of 1890 a 24-inch redwood pipe 5½ miles in length was built at Ogden, Utah. In 1911, 4,674 feet of this line was replaced, but is still used as an overflow pipe from a reservoir. On a few summits, where not always full, the pipe has decayed badly, but with these exceptions the original line is in general very well preserved. When inspected in October, 1912, repairs were being made at a river crossing, where settling of the bridge had caused the splitting of many staves, which were being replaced. These staves were not rotted materially, but about one-eighth of an inch of the interior was so softened that it could be easily scraped off with a knife. Many of the staves were also split back from the saw kerf several inches, thus permitting the outer portion to decay more rapidly than the rest of the stave. This portion of the pipe at another point, where supported on a trestle protected from the sun by rough boards, showed the staves to be in a perfect state of preservation. The pressure at the latter point was light, as indicated by the spacing of bands, which were 1 foot apart.

A 48-inch redwood pipe, 2,000 feet long, built by the Bear Valley Irrigation Co., at Redlands, Cal., in 1891, was in continuous use until the summer of 1912, when it was replaced by a ditch. About 500 feet of this pipe at the upper end was completely buried, and of the remainder of the line which was originally supported 200 to 300 feet became partially covered by slides from the slopes. Where in contact with the earth the staves of the pipe were considerably decayed, but in other parts the wood was well preserved at the time of its removal.

In 1892, 48,193 feet of 24-inch redwood pipe was built for the Butte (Mont.) Water Co. Eugene Carrol, manager of the company, under date of January 15, 1913, states:

> During the past season we had occasion to open this pipe to make a new connection at the lower end and found it in excellent condition. As far as we know, the whole line is in excellent condition, and there has been no deterioration noticeable. Of course, the bands are rusted considerably, and when it is necessary to remove a band a new one has to be substituted. At one point where earth was hard to get we backfilled with broken rock, which allowed the air to get to the outside of the pipe. It is our experience that this caused the deterioration of the wood, and the broken rock was removed and replaced

with sand and earth, carefully tamped around the pipe. This apparently stopped the decaying of the wood. The Basin Creek line has now been in service 20 years, and it is impossible to estimate how much longer it will last, as at present it has shown no signs of giving out.

An 18-inch redwood pipe 8,600 feet long was built at Logan, Utah, also in 1892. This is still in service, but its condition is not known, though presumed to be good.

Roswell Snow, superintendent of waterworks, Provo, Utah, under date of January 30, 1913, writes as follows concerning a redwood pipe:

I have been in touch with this pipe for the past eight years, and have been taking note of it in the different ground in which it is laid. I find in the clay ground it seems to be nearly as good as new, in gravelly ground it is in fairly good shape, but in loam and light soil it is nearly gone. It has been in use nearly 25 years and I would think that the pipe in the clay ground would last 20 years longer.

In the years from 1897 to 1901 and 1902, the Union Hollywood Water Co. at Los Angeles, Cal., installed continuous stave redwood pipe, which, according to F. C. Finkle, consulting engineer, who examined it in 1910, was rotted to a mere shell from one-sixteenth to three-sixteenths of an inch thick. This was in a gravity system under a head of not to exceed about 50 feet and in places considerably less. He states that of another redwood pipe installed at Long Beach, Cal., in 1900, 4,000 feet or so was replaced in January, 1912. This, under his observation from 1908 to 1912, was found to be badly decayed, and the bands were seriously corroded, though none failed. It was laid in a compact soil which contained some alkali. The pressure ranged from 20 to 40 pounds.

In the fall of 1895, 7½ miles of fir pipe was built at Astoria, Oreg.[1] In 1905 portions of this line were found to be badly decayed, and in 1911 it was all replaced by another pipe of redwood.

G. W. Lounsberry, of the Astoria Water Commission, states:

Where the line was buried to a depth of 2 feet or more in fine-grained sand or clay it lasted much better than where it was laid in black soil mixed with decayed vegetation or where it was laid in shale. This, regardless of the water pressure, and the staves in the bottom where there was a constant flow of water were equally affected with those on top that at times were dry on account of the pipe not running full.

The 72-inch fir pipe, 3 miles in length, built for the Pioneer Electric Power Co. at Ogden, Utah, in 1897 is still in service. Repairs in the nature of an occasional new stave have been necessary for several years, and in the month of October, 1912, when it was inspected, arrangements were being made to replace the upper end where the pressure is light. This pipe is in many places but little below the hydraulic gradient and in most parts but lightly or partially covered.

[1] Trans. Amer. Soc. Civ. Engin., 36 (1896), p. 1; 58 (1907), p. 65.

At one point some distance below the intake where uncovered for repairs, the staves of the lower half of the pipe were found to be decayed to a mere shell. The 4-inch spacing of bands indicated a fairly good internal pressure. The backfill was stony. Near the dam, where the pressure was not more than 10 or 15 feet, the staves were badly decayed, and it is probable that much of the pipe was in poor condition at this time. On a bridge where it had always been fully exposed there was no appreciable decay of the staves other than at leaky joints, and the same was true along the top of the pipe where exposed or covered with only an inch or two of coarse soil, which permitted it to remain dry.

R. M. Hosea, chief engineer of the Colorado Fuel & Iron Co., writes as follows about a pipe several miles long:

> The oldest line we have—28 inches in diameter—was built in 1900. For five years past it has been repaired in places by inserting new staves where old ones were badly rotted on the exterior. This allows bands to sink into soft wood and staves to leak. The rot progresses until one-half to three-fourths of the wood is rotted. It occurs in patches, or on certain staves their full length, according to amount of pitch in the wood, or some variation in its quality. This pipe was of Texas pine staves. I should add also that the bands become rapidly corroded where leaks have formed and ground is moist, and I should doubt a life of 20 years for this line even if repairs are kept as above indicated, where we are constantly putting in new fir staves and some new bands.

This pipe is laid in fine adobe soil and covered to a depth of 2 feet or more.

By the side of the pipe just mentioned, and under the same conditions, a 48-inch fir pipe was laid in November and December, 1906. Mr. Hosea says that in three years it was decayed sufficiently to cause leaks. When inspected in October, 1913, it showed serious decay, and was being incased with reinforced concrete. This pipe was covered with the adobe soil from 18 inches to 2 feet deep, and where examined was under a head of perhaps 30 feet or more. In most instances the decay extended half way through the staves. Sometimes a sound stave occurred, while those on each side of it might be badly rotted. The bands were in good condition and only slightly corroded. Twenty-five other pipe lines built by this company about the same time as this one have also been incased with concrete, decay in the case of each having made more or less progress.

Under date of May 15, 1912, L. B. Youngs, water superintendent of Seattle, Wash., writes as follows:

> The first wood pipe that we installed in this city was put in 12 years ago, and was made out of our native timber here, known as Douglas fir. * * * In clay soils the pipe lasts fairly well, and I would place its life at from 12 to 20 years; in sandy and gravelly soils I would place its life at from 7 to 12 years. However, in the case of large pipe with individual bands the cost of reinstallation would be the cost of the wooden part of the pipe only, as we find the iron bands to be in good condition after 10 to 12 years' service, so that they could be used for the new wood.

In 1901 the National Sugar Manufacturing Co. at Sugar City, Colo., built about 4 miles of fir pipe, which was covered by earth to a depth of 2 to 4 feet. The one-half inch steel bands began to give way after six years, more of them each succeeding year, causing frequent breaks in the line and much annoyance, especially in winter. In 1910 this line was rebanded with $\frac{5}{8}$-inch round, refined bar iron.

A 24-inch fir pipe 3 miles long was built for the Pueblo (Colo.) waterworks in 1904. This was banded with one-half inch soft steel bands, buried from 1 to $3\frac{1}{2}$ feet deep, a part in shale, and some in an adobe loam soil. About seven or eight years later the bands began to fail. Four thousand feet of this pipe was replaced in 1912, and the remainder was taken up in 1913.

The foregoing examples are all continuous stave pipes, but an investigation of the life of machine-banded pipe shows a like variability, the length of service being dependent altogether upon conditions. Instances are frequently published illustrating the extremely long life of the old bored log pipes which were used in the early days, and there is probably a considerable amount of machine-banded pipe which under favorable conditions has now been in use for 30 years or more, while in a great many places the conditions of service have been such as to render the life very short.

A. F. Doremus, of Salt Lake City, Utah, states that flat-banded bored pipe laid for the city water system of Tooele, Utah, in 1890 is still generally in good condition, except in places where it was not kept wet. This system now consists of about 20 miles of wood pipe, much of which is of the modern machine-banded stave type. Some of the modern pipe has had to be replaced in three years. A great many instances might be cited where the life of machine-banded pipe has been only from 4 to 10 years. Based upon the experience in Spokane, Wash., the life of machine-banded wood pipe is given as ranging from 4 to 12 years.[1] Such short life in most instances is probably due to bad judgment in the matter of location or the use of pipe under conditions altogether unfavorable to its life.

Frequently in connection with municipal water systems pressures are imposed far in excess of those for which the pipe was designed, thus hastening its destruction. For irrigation systems the demand by some of the promoting companies for an extremely cheap pipe without particular consideration as to its durability has probably in some instances led the manufacturers to incorporate poor material in the pipe supplied.

The unfavorable conditions of whatever nature, singly or together, result most frequently in the decay of the pipe, thus shortening its life. The decay of wood pipe is probably due primarily to the

[1] Ann. Rpt. Water Div., Dept. Public Utilities [Spokane, Wash.], 1911.

growth of fungi, though possibly certain forms of bacteria may assist in the final destruction of the wood cells. The growth of fungi to an extent detrimental to the life of the wood requires a favorable combination of moisture, air, and heat. The exclusion of any one of these beyond certain limits inhibits their growth.

From this it follows that with pipes buried in the ground the wood will endure longest where the air is most nearly excluded either by a high internal pressure which completely saturates it or by a deep covering of very fine soil. In accordance with the foregoing statement, experience, which might be illustrated by many specific examples, shows that in contact with the soil wood pipe decays more rapidly under a light head than it does under heavy pressure, and other things being equal, it usually decays more rapidly in a porous open soil, such as sand or gravel, than it does in a fine soil of silt or clay, because the finer soil is more effective in excluding the air. Experience appears to indicate also that wood decays more rapidly in a loamy soil, rich in humus or partially decayed organic matter, than it does in one containing little or none. This is probably due to the fact that the presence of organic matter affords more favorable conditions for the development of fungus growths and bacteria.

Pipes fully exposed to the atmosphere and free from contact with the soil will, as a rule, be too dry on the exterior to favor the development of fungus spores, and so long as the outside of a pipe remains dry no appreciable decay will occur, even though the internal pressure is very light. Decay of exposed pipes almost invariably starts at the ends of staves, as a result of leaky joints. Where water leaks out and runs down over the outside of the pipe favorable conditions are afforded for the growth of algæ, which usually get a start, then mosses may begin to grow in the soil that collects on such spots, and decay spreads to adjoining staves. Bruising the staves in handling or injuring by too tight cinching of bands renders them more susceptible to infection by the spores of wood-destroying fungi, thus hastening decay. The life of exposed pipes may be prolonged by promptly stopping all leaks as they develop and by keeping the exterior dry. The decay of buried pipes has also in some instances been arrested by removing the covering and leaving them exposed.

The asphaltum or tar coating applied to machine-banded pipe, while intended primarily as a protection against corrosion of the bands, doubtless helps also to some extent in preserving the wood. Until recently the practice has been to leave the ends of wooden sleeve couplings untreated. These couplings almost invariably decay long before the main pipe. This may indicate that infection by wood-destroying organisms starts principally where the coating is absent, though less perfect saturation of the wood in the sleeves may be the more largely responsible for the early decay, as it may be noted

also that decay occurs at summits of pipe lines where air accumulates much sooner than at depressions.

The practice of coating continuous stave pipe has not been common, but in a considerable number of cases some treatment has been applied for the purpose of preserving the wood. There is wide difference of opinion as to the value of such treatment, and the effectiveness for the purpose intended may depend also greatly on what is used and upon how and when it is applied.

On exposed portions of new pipes the United States Reclamation Service has used a paint consisting of 6 pounds of red oxid mixed with 1 gallon of boiled linseed oil. One gallon of the paint was sufficient for two coats on 125 square feet of pipe. On top of the pipe where exposed to the sun and where water from leaky joints runs down over it this paint does not last long, much of it being gone in two years. Repainting while the pipe is in use is usually not practicable, because oil paint will not adhere readily to wet material. The use of paint on exposed pipes under ordinary conditions probably adds very little to their life.

The Denver Union Water Co. on new work in 1911, used a primary coat of linseed oil and lampblack, and a secondary coat consisting of an asphaltum mixture. In March, 1914, the "Mabton siphon," which had been uncovered the fall previous on account of decay, was given two coats of coal tar tempered with creosote. The mixture was applied by a machine which pumped the hot mixture through a hose and nozzle, shooting it on to the pipe with considerable pressure. The same machine was used in cleaning the soil and decayed material from the pipe before painting. Other instances might be cited showing the use of asphaltum or tar on old pipes after uncovering. The cost of the work is considerable and its value is questionable, particularly where pipes are to remain exposed.

The staves of a 50-inch pipe built at Burbank, Wash., December, 1912, were creosoted before construction. This pipe was buried in sandy soil and operates under little or no internal pressure. The cost of treating the staves was said to be $24 per thousand. Carbolineum was used as an exterior coating on part of a 48-inch pipe built at Wenatchee in 1907, and on a 12-foot pipe built in Oswego County, N. Y.

Where pipes are to be placed in contact with the soil, and where the internal pressure is not sufficient to insure complete saturation of the staves, it is probable that their durability may be increased by treating with some preservative.

A difference in the effectiveness of materials for this purpose is indicated by the following example: In 1890 a 54-inch pipe of Texas pine was built for the Bessemer Ditch Co., at Pueblo, Colo. About 1,500 feet of this was subjected to light pressure, and at times the pipe

was only partially filled. This portion was badly decayed in five years, and 1,100 feet of it was replaced by redwood in 1895. With the exception of a 100-foot section near the middle of the new part, the redwood was painted with hot coal tar. The 100-foot section was painted with asphaltum paint. According to Mr. C. K. McHarg, secretary of the company, the pipe coated with tar was found to be perfectly sound when examined in 1910, while the 100-foot section was badly decayed and had to be replaced.

Contrary to the theories commonly held 30 years ago, it has been found that the durability of wood pipe is usually dependent on the life of the wood rather than on the life of the bands. Only in rare instances, some of which have been cited, have the bands failed first. Corrosion of the bands being a chemical action, requires the presence of moisture and oxygen. It usually occurs most rapidly where pipes are buried and the backfill is wet, under conditions which, as a rule, are most favorable for the life of the wood. Corrosion is greatly accelerated by the presence of alkali in the soil. The early failure of bands in the few instances cited was due chiefly to this cause. Under such conditions the bands almost invariably fail at the bottom of the pipe.

Wearing out of the wood as a factor in the durability of pipe is a matter of small consequence, though it must at times be recognized. A 48-inch spruce pipe on the Catlin Canal in Colorado, in 23 years' use, was worn nearly through the staves for a distance of nearly 100 feet at the outlet end. The inlet end of a redwood siphon near North Yakima, Wash., had to be lined with sheet iron to preserve it from wearing action of grit, and one of the large pipes on the King's Hill project in Idaho was nearly cut in two at one place by the circular movement of chips and débris floating on the surface near the intake where the pipe was not full.

With so many influences affecting the life of wood pipe no attempt should be made to strike an average of durability except in cases where attending conditions are known to be the same. Where pipes are fully exposed and supported free from all contact with the soil the conditions are much less variable than otherwise, and a life of at least 20 years may be quite reasonably expected for either fir or redwood if properly maintained. If placed in the ground or in contact with the soil, the life of wood pipe may, under very favorable conditions, be much greater than 20 years, otherwise it may be a great deal less. In contact with soil the durability is nearly always a matter of some uncertainty.

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